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VLF/LF REFLECTIVITY OF THE POLAR IONOSPHERE, 4 May - 20 September 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a summary of high-latitude ionospheric reflectivity data, as observed by the USAF high-resolution VLF/LF ionosounder operating in northern Greenland. Ionospheric reflectivity parameters, including reflection heights and coefficients, are presented as a function of time of day. Riometer and magnetometer measurements of the polar propagation environment are presented as supplementary data.

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Preface

The authors thank in particular Mr. Duane Marshall of Megapulse, Inc., for help with the equipment that made the measurements possible, and Mr. Bjarne Ebbesen of the Danish Meteorological Institute for the outstanding operation at Qanaq, Greenland.

Appreciation is also extended to the Danish Commission for Scientific Research in Greenland for allowing these measurements to be conducted and to Jorgen Taagholt and V. Neble Jensen of the Danish Meteorological Institute's Ionospheric Laboratory for their continued cooperation in this program.

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Illustrations

VLF/LF Reflectivity of the Polar Ionosphere

4 May – 20 September 1980

1. INTRODUCTION

This report provides a summary of high latitude ionospheric reflectivity data, as observed by the USAF's high resolution VLF/LF ionosounder operating in northern Greenland.[1,2] As shown in Figure 1, the transmitter is located at Thule Air Base, Greenland (76° 33'N. Lat., 68° 40'W. Long.), and the receiving site is 106 km north at the Danish Meteorological Institute's Ionospheric Observatory in Qanaq, Greenland (77° 24'N. Lat., 69° 20'W. Long., Geomagnetic Lat. 89° 06'N). The ionosounding transmissions consist of a series of extremely short (approximately 100 μsec) VLF pulses, precisely controlled in time, and radiated from a 130 m vertical antenna. At the receiving site, orthogonal loop antennas are used to separate the two polarization components of the ionospherically reflected skywave signal. One antenna, oriented in the plane of propagation, is used to sense the groundwave and the transmitted or "parallel" polarization component of the skywave. The second loop, nulled on the groundwave, senses the converted or "perpendicular" polarization skywave component. The signal from each of the antennas is digitally averaged to

(Received for publication 20 March 1981)

1. Lewis, E.A., Rasmussen, J.E., and Kossey, P.A. (1973) Measurements of ionospheric reflectivity from 6 to 35 kHz, J. Geophys. Res. 78:19.

2. Kossey, P.A., Rasmussen, J.E., and Lewis, E.A. (1974) VLF pulse ionosounder measurements of the reflection properties of the lower ionosphere, Akademie Verlaq, COSPAR, July.

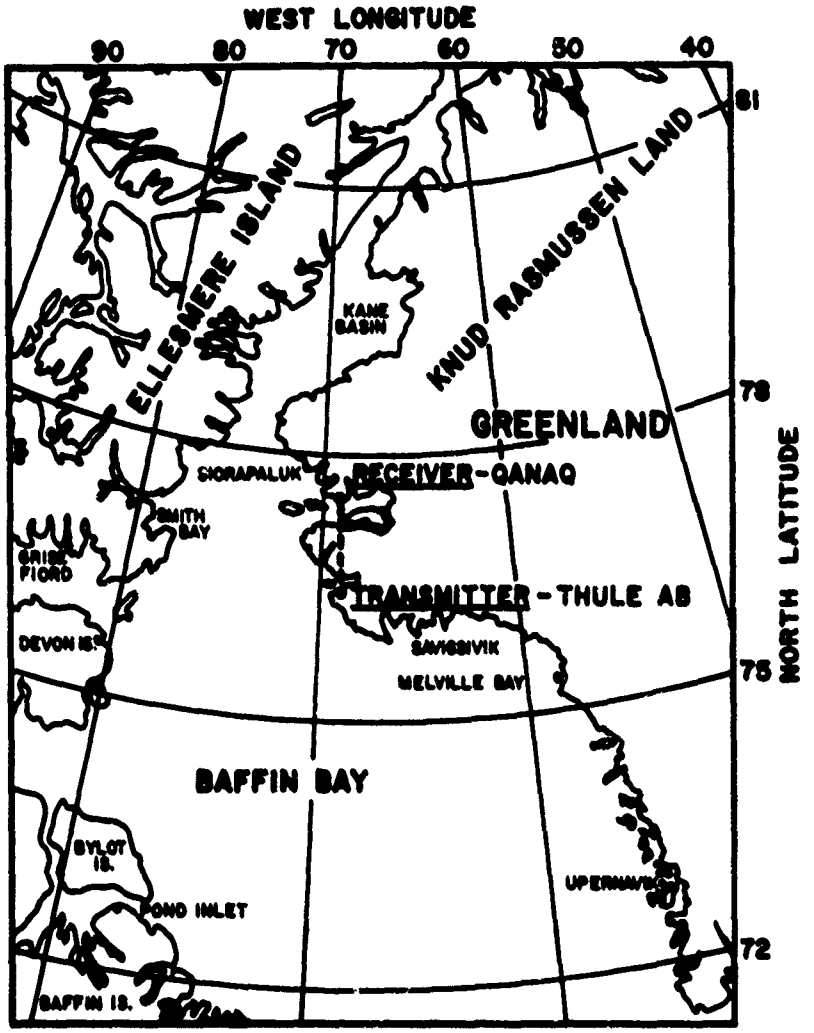

Figure 1. Geometry of the Propagation Path

improve the signal-to-noise ratio of the individual received waveforms before they are recorded on magnetic tape. An example of the observed waveforms is given in Figure 2, where the "parallel" waveform (Figure 2a) consists of a groundwave propagated pulse, a quiet interval containing low level, off path groundwave reflections, followed by the first-hop parallel skywave component. The perpendicular waveform is shown in Figure 2b.

Ionospheric reflection parameters are derived by computer processing of the ground and ionospherically reflected waveforms with allowance made for factors such as ground conductivity and antenna patterns (see Section 4).

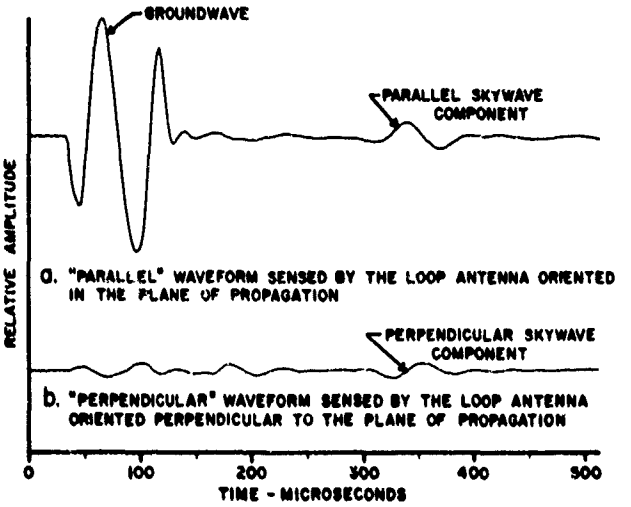

Figure 2. Example of the Observed Waveforms

Although the data are recorded about once per minute, for this report the waveforms are averaged into 2-hr time blocks with the exception of the three-dimensional waveform presentations (Section 2.2). The resulting information is presented in a weekly format (Figures 3 through 22 as described below).

2. OBSERVED WAVEFORMS

2.1 Weekly Example of Individual Waveforms

In part A of Figures 3 through 22, a set of averaged parallel and perpendicular waveforms is presented for the time block centered near local noon of the indicated day. Each of these waveforms is comprised of 256 digitally averaged points spaced 2 μsec apart. In part B of the figures, the groundwave Fourier amplitudes are shown as a function of frequency. Although the data presented in parts C through L of the figures are generally limited to frequencies in the first, or principal, lobe of the spectrum, information at higher frequencies can be used when sufficient signal-to-noise conditions exist. There is, however, a frequency range around each spectral null where insufficient signal exists for measurements.

2.2 Three-Dimensional Waveform Presentation

A three-dimensional display of the recorded $\parallel$ waveforms covering each weekly period is shown in Part R of each figure and the corresponding $\perp$ waveforms are shown in Part S. For these plots the data has been averaged into 15-min time blocks.

3. REFLECTION HEIGHTS

The group mirror height (GMH) of reflection was obtained by determining the group delay of the skywave relative to the groundwave and attributing the time difference, by simple geometry (assuming a sharply bounded mirror-like ionosphere) to a difference in propagation distance. As discussed in Lewis et al,[1] the group delay can be defined as the rate of change of phase with frequency. For the GMH data presented in this report, a finite frequency difference of 1.0 kHz was used, and the corresponding phase difference as a function of frequency for the groundwave and both skywave signals was obtained by Fourier analysis of the respective pulses. The GMH calculations took into account ground conductivity (10^{-3} mho/m is assumed), and the corrections of Wait and Howe[3] were applied. Group mirror heights, obtained from the parallel and perpendicular waveforms, are plotted as a function of frequency in parts C and D of Figures 3 through 22. The GMH's are also presented as a function of time-of-day for the average frequency of 16.5 kHz in figure parts E and I. The parallel GMH's in part E are shown along with an average reflection height for reference purposes. Each point of the reference height is a weekly average, by time block, for the 7-day period indicated. The corresponding perpendicular GMH's, part I of the figures, are also shown with the weekly average for comparison. Part G gives the average, by time block, for the daily parallel GMH data of part E, and part K gives the corresponding perpendicular GMH averages from the daily data of part I.

4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients[4] were obtained by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

The reflection coefficient $\|R_\|$ was obtained from analysis of the parallel skywave component and is plotted as a function of frequency in part C of Figures 3 through 22. The $\|R_\|$ coefficient for 16 kHz is plotted as a function of time-of-day in part F along with the average of the indicated week for reference purposes.

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3. Wait, J.R., and Howe, H.H. (1956) Amplitude and Phase Curves for Ground-Wave Propagation in the Band 200 Cycles per Second to 500 Kilocycles, Nat. Bur. Stand. U.S. Circ. No. 574.

4. Budden, K.G. (1961) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.

From the perpendicular skywave pulse, the coefficient $_{\parallel}R_{\perp}$ was obtained and appears as a function of frequency in part D. The 16 kHz $_{\parallel}R_{\perp}$ is shown along with its reference in part J. Parts H and L present the average, by time block, of the daily $_{\parallel}R_{\parallel}$ and $_{\parallel}R_{\perp}$ data presented in parts E and J, respectively.

For certain coefficient data points, plotted as asterisks (*), the reflection coefficient appears without a corresponding GMH. For these particular data, only the skywave-groundwave ratios could be obtained as the skywaves were too weak to provide reliable group delay information. The reflection coefficients were therefore estimated using a nominal GMH of 80 km in the calculations. These estimated coefficient values are included in the averages presented in parts H and L, but the assumed heights are not used in the GMH averages shown in parts G and K.

5. SUPPLEMENTARY INFORMATION

For purposes of comparison and interpretation, certain supplementary data are presented. Part M of the figures shows the magnitude of the horizontal component of the polar magnetic field as recorded on a three-axis fluxgate magnetometer and part N presents 30-MHz riometer data, an indicator of D-region particle precipitation. These supplementary data were recorded at 30-sec intervals by RADC/EEP at Thule AFB; the curves represent the average of 10-min periods. The solar zenith angle is given in part O of Figures 3 through 22 for the indicated mid-week date.

6. IONOSPHERIC DISTURBANCE DATA

During the period covered by this report, solar activity continued at a low level. The strongest event recorded occurred on 17 July (DAY 199). Although no riometer data were available for plotting, it is known that absorption reached 2 dB on 18 July (DAY 200). The effects of other smaller energetic particle events can be seen in the data beginning on the following dates. None of these events produced more than 0.5 dB riometer absorption.

7 June (DAY 159, Figure 7)	17 July (DAY 199, Figures 13-14)
21 June (DAY 173, Figures 9-10)	6 Aug (DAY 219, Figure 16)
29 June (DAY 181, Figure 11)	14 Aug (DAY 227, Figures 17-19)
6 July (DAY 188,(Figure 12)	31 Aug (DAY 244, Figure 20)

The transient effects of Sudden Ionospheric Disturbances (SID) can be seen in many of the three-dimensional waveform plots. These short-lived events were particularly evident during the week 11 May (DAY 132) – 17 May (DAY 138), Figure 4.

During ionospheric disturbances when enhanced ionization causes a lowering of the reflection heights, the skywave moves closer to the groundwave and can merge with constant off-path groundwave reflections (described in Section 1, Introduction). During these periods, the off-path reflections are computer subtracted from the waveforms to avoid contamination of the skywave data. This subtraction technique was used in the parallel and perpendicular waveform data for the weekly periods beginning on:

DAY 153 (Figure 7)
DAY 167 (Figure 9)
DAY 174 (Figure 10)
DAY 181 (Figure 11)
DAY 188 (Figure 12)
DAY 195 (Figure 13)
DAY 202 (Figure 14)
DAY 209 (Figure 15)
DAY 216 (Figure 16)
DAY 223 (Figure 17)
DAY 230 (Figure 18)
DAY 237 (Figure 19)
DAY 244 (Figure 20)

7. ADDITIONAL COMMENTS

This report is one of a series.[5-21] Comments and suggestions for improving its usefulness should be addressed to the Propagation Branch (EEP) Electromagnetic Sciences Division, Deputy for Electronic Technology (RADC/EEP), Hanscom AFB, Massachusetts 01731. A report[22] has been published which gives a detail description of the VLF/LF propagation disturbances produced by energetic particle events during the period 1974 - 1977.[4-14]

(Because of the large number of references cited above, they will not be listed here. See References, page 94.)

Figures 3 through 22 follow in sequence on the following pages.

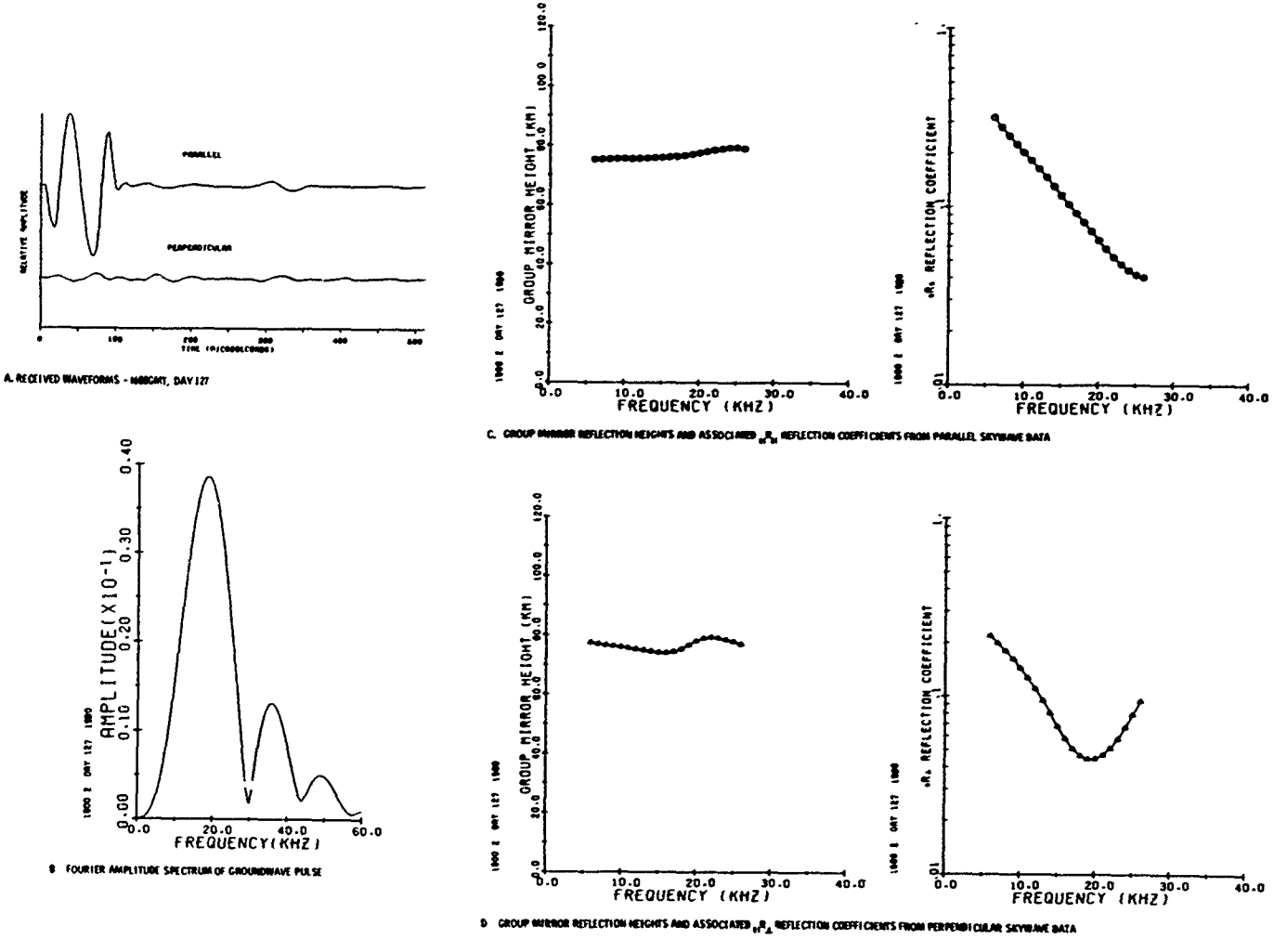


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 125 (4 May) — DAY 131 (10 May) 1980

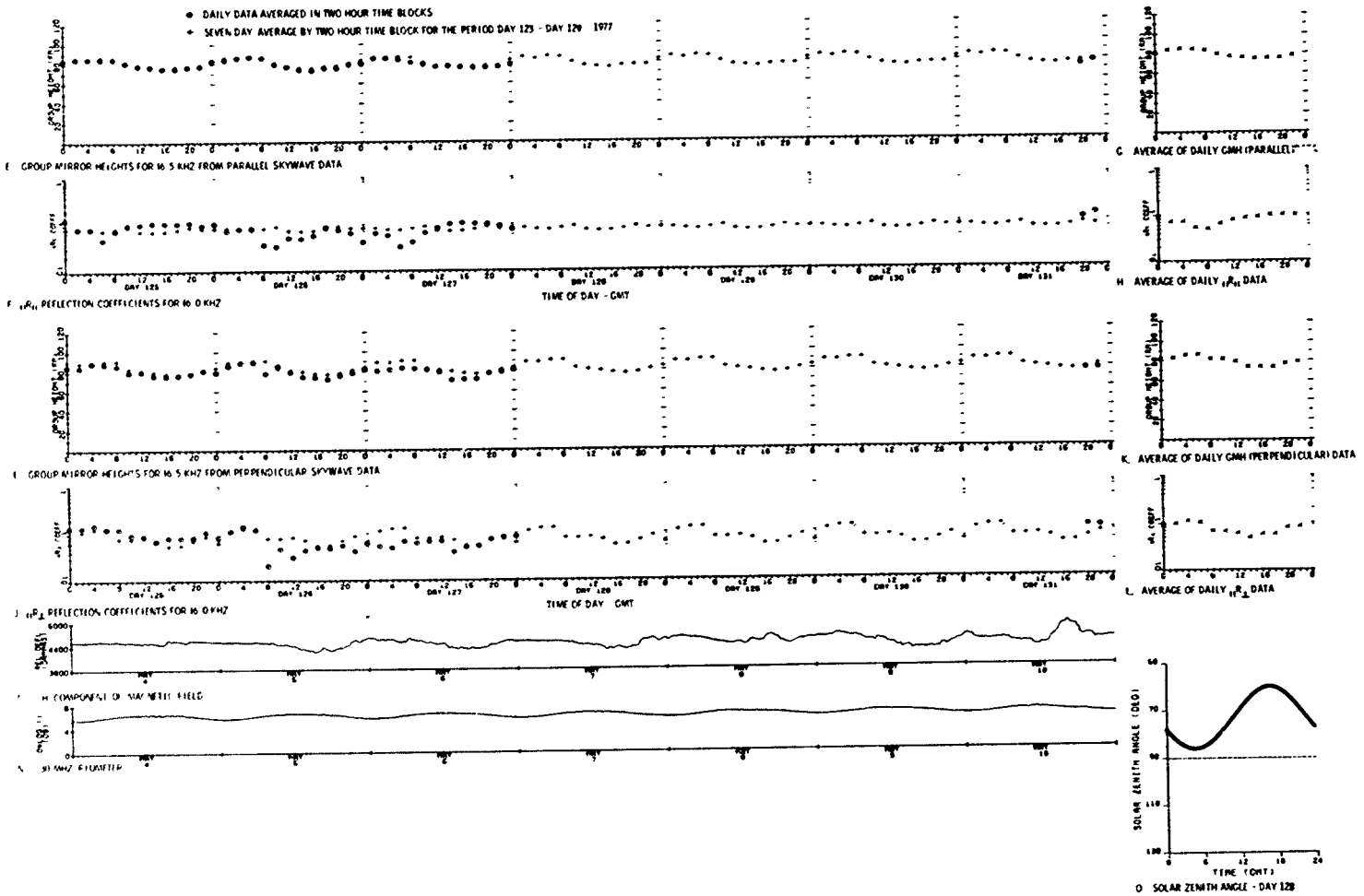


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 125 (4 May) — DAY 131 (10 May) 1980 (Cont)

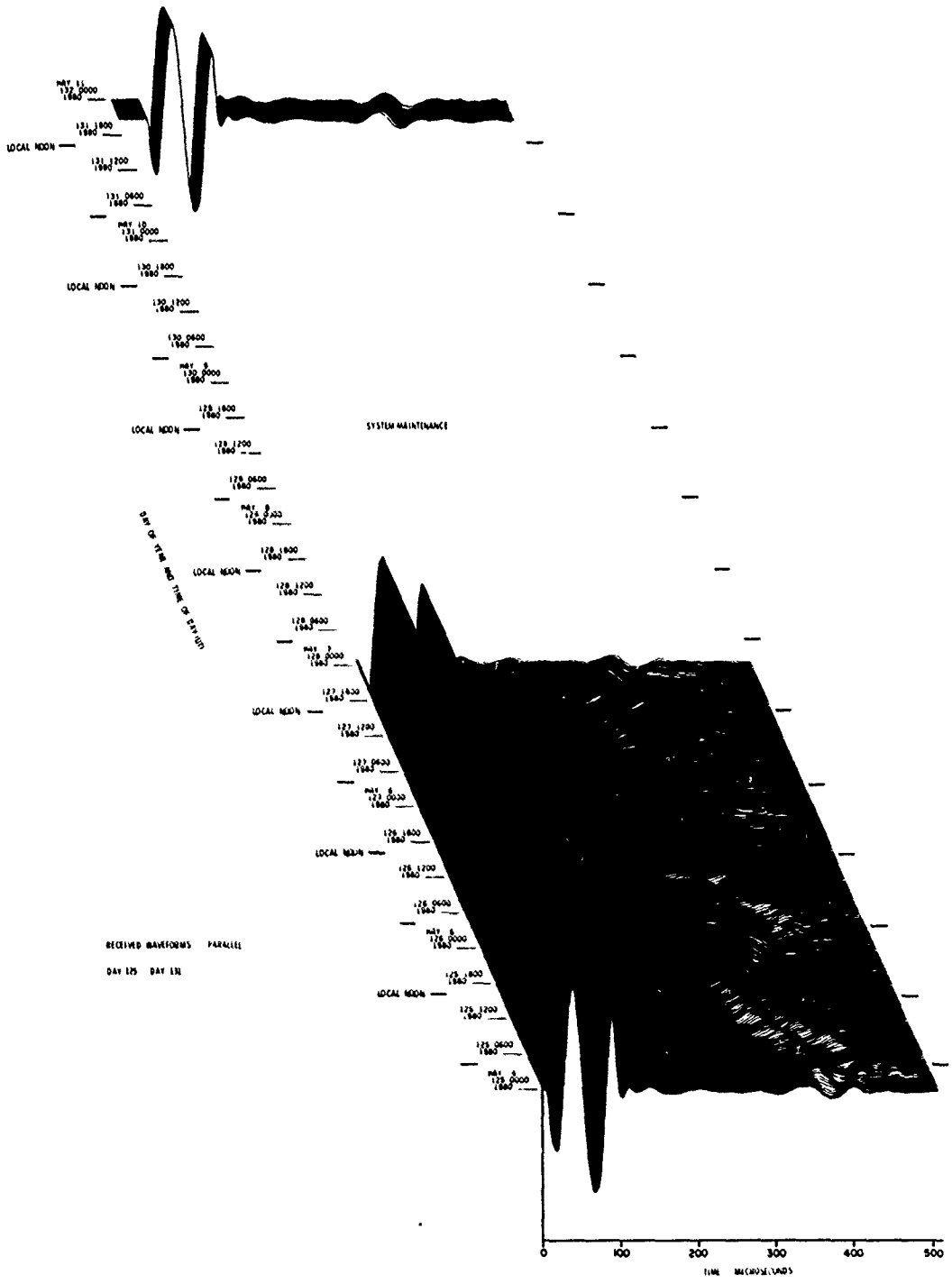


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 125 (4 May) – DAY 131 (19 May) 1980 (Cont)
Part R. || Waveform Display

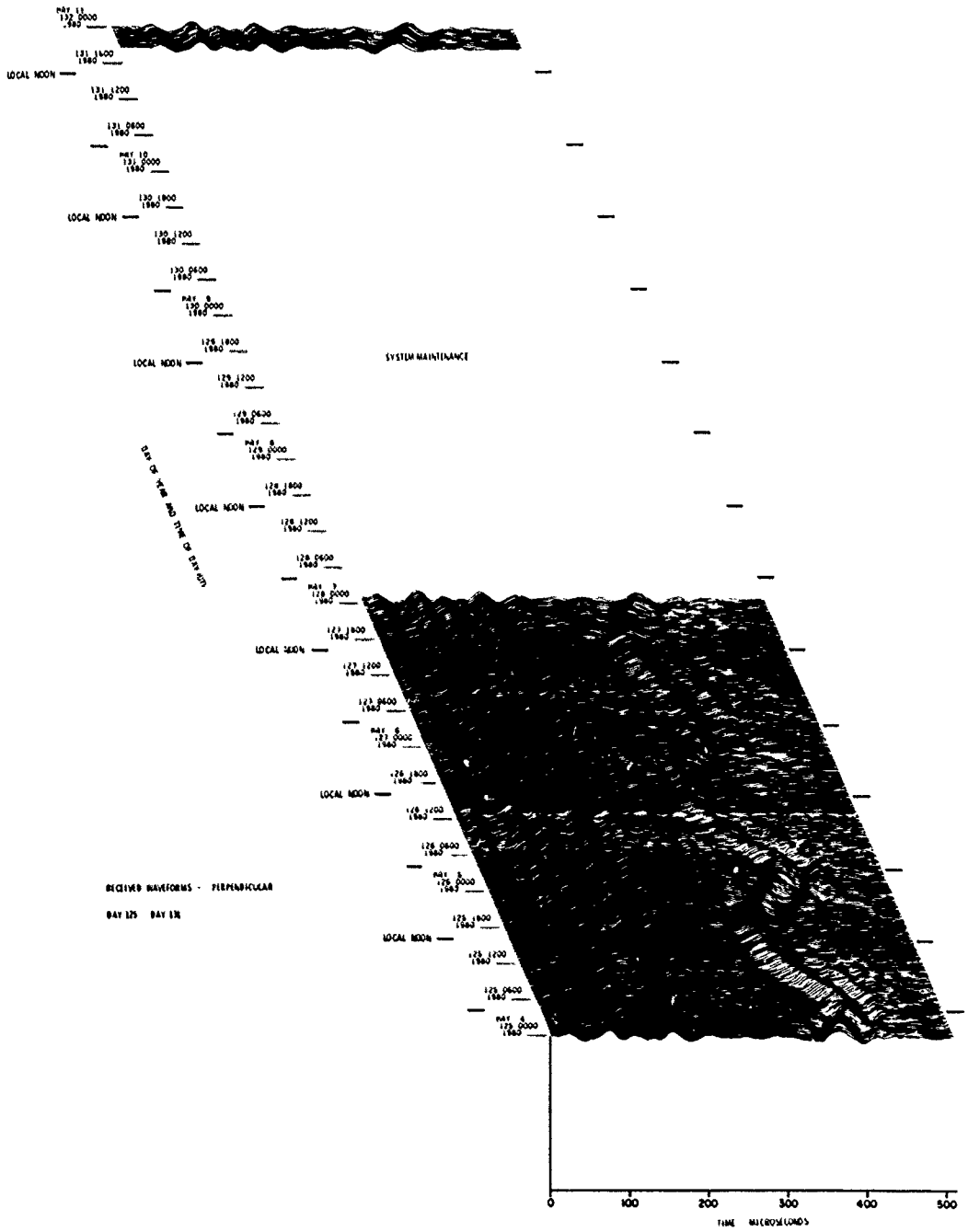


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 125 (4 May) – DAY 131 (19 May) 1980 (Cont)
Part S. ⊥ Waveform Display

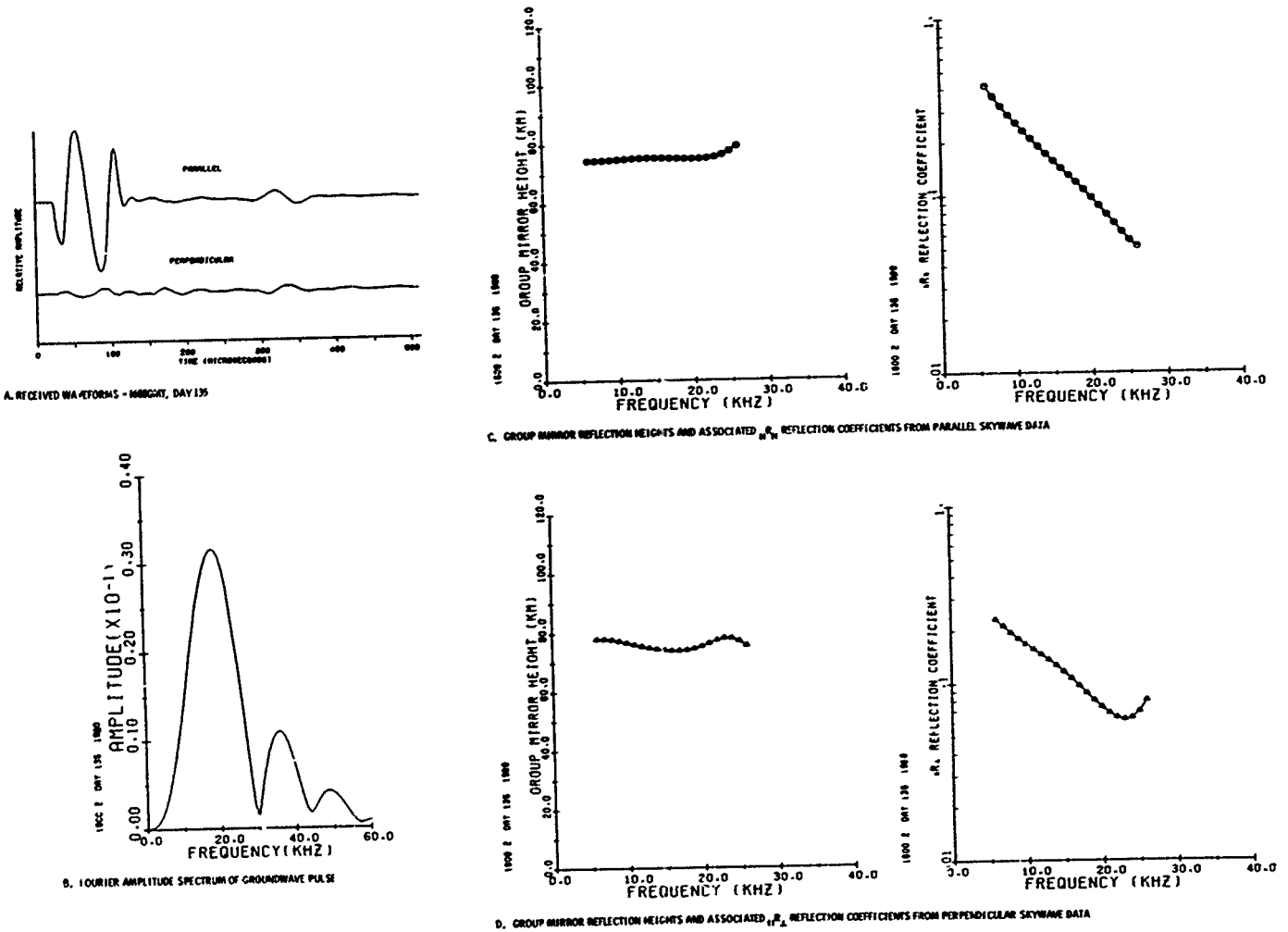


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 132 (11 May) – DAY 138 (17 May) 1980

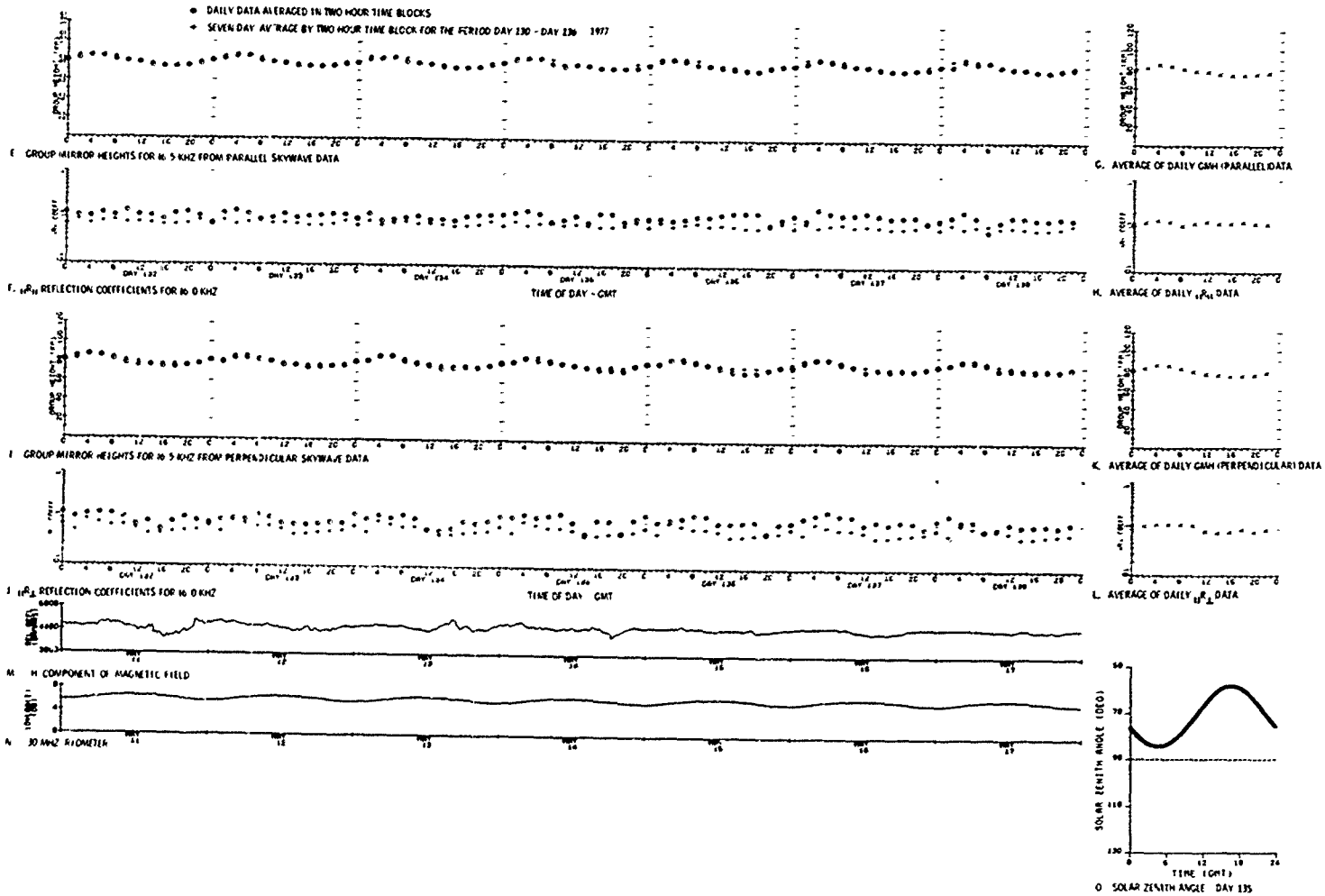


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 132 (11 May) — DAY 138 (17 May) 1980 (Cont)

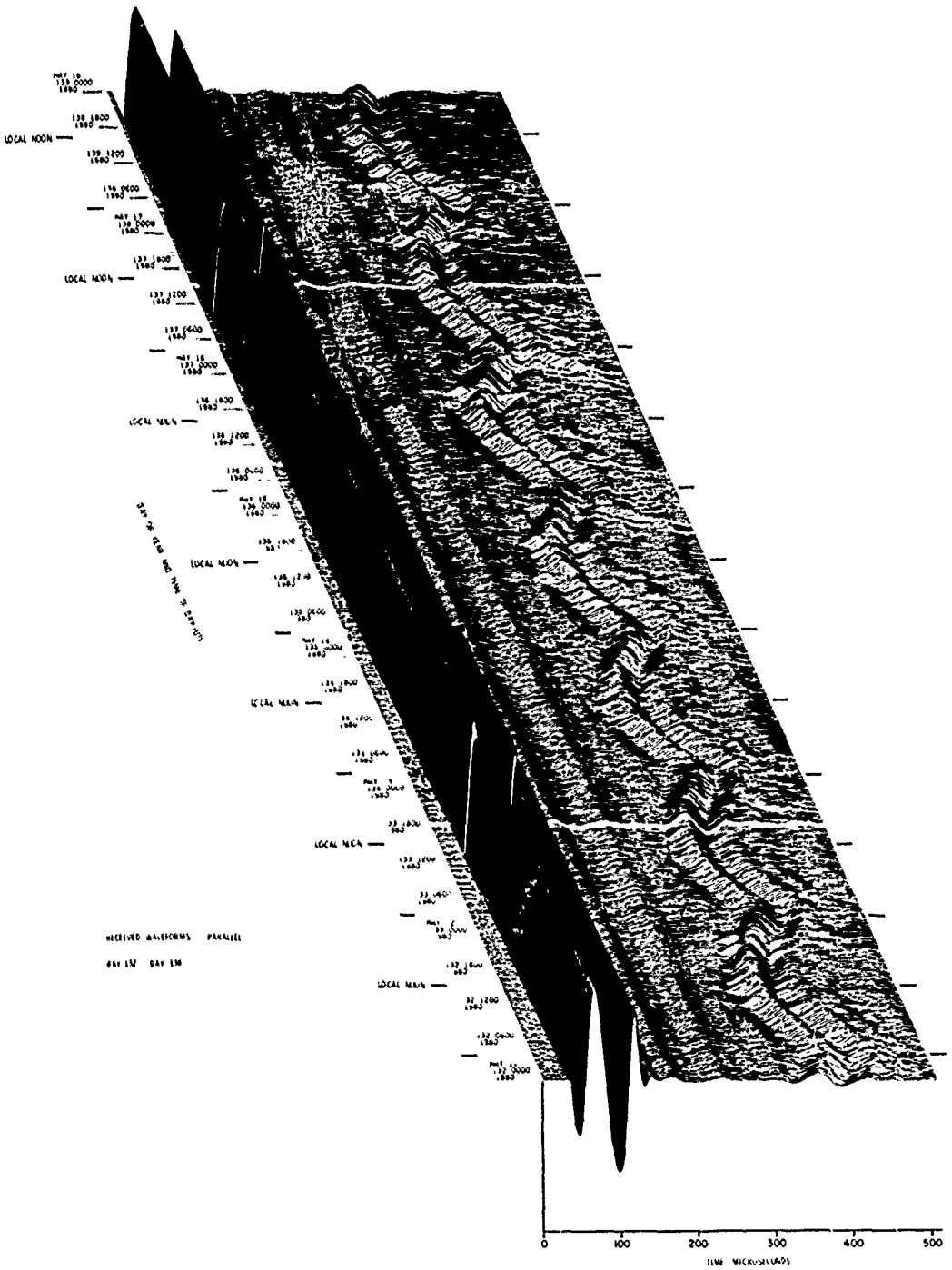


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 132 (11 May) – DAY 138 (17 May) 1980 (Cont)
Part R. || Waveform Display

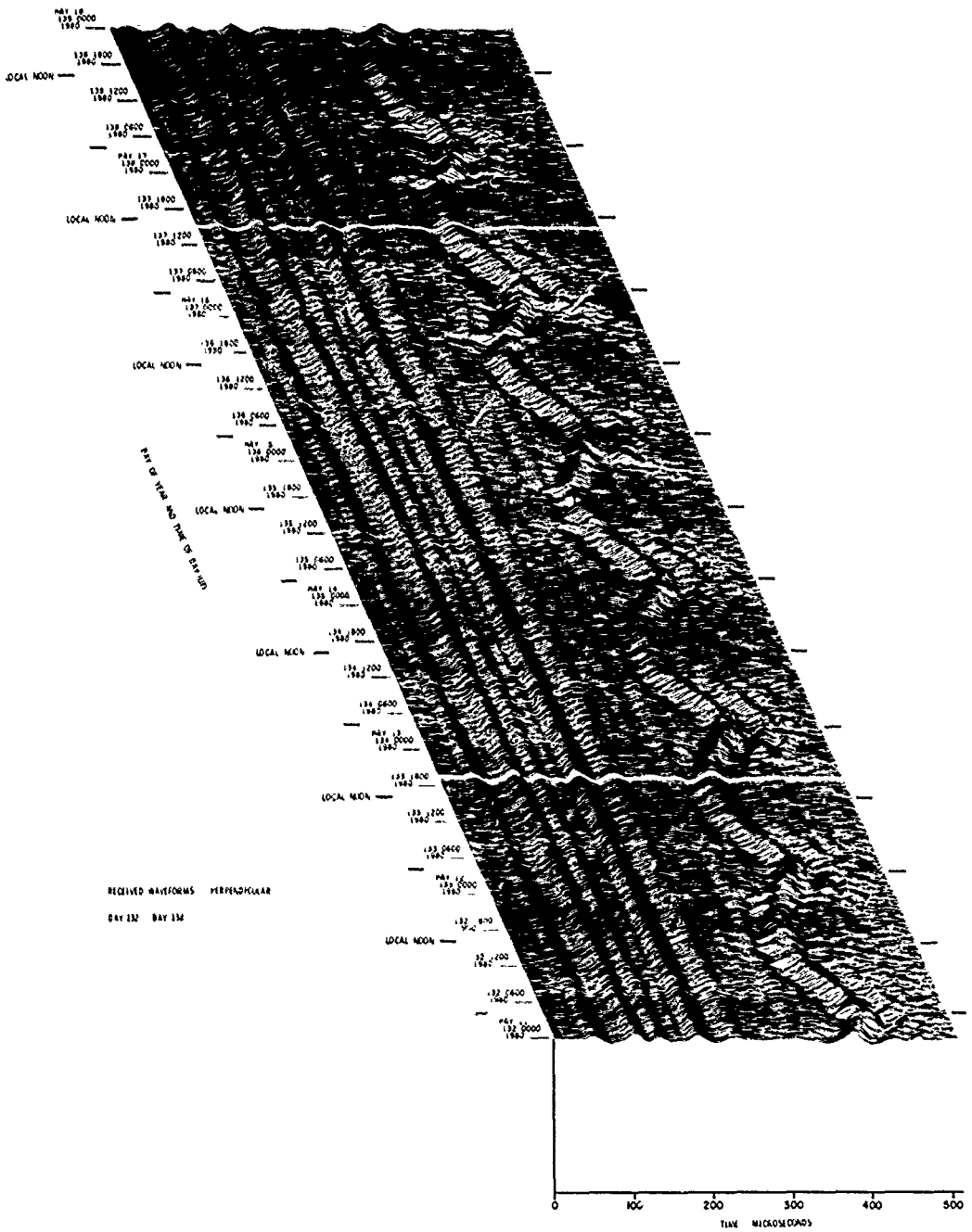


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 132 (11 May) – DAY 138 (17 May) 1980 (Cont)
Part S. ⊥ Waveform Display

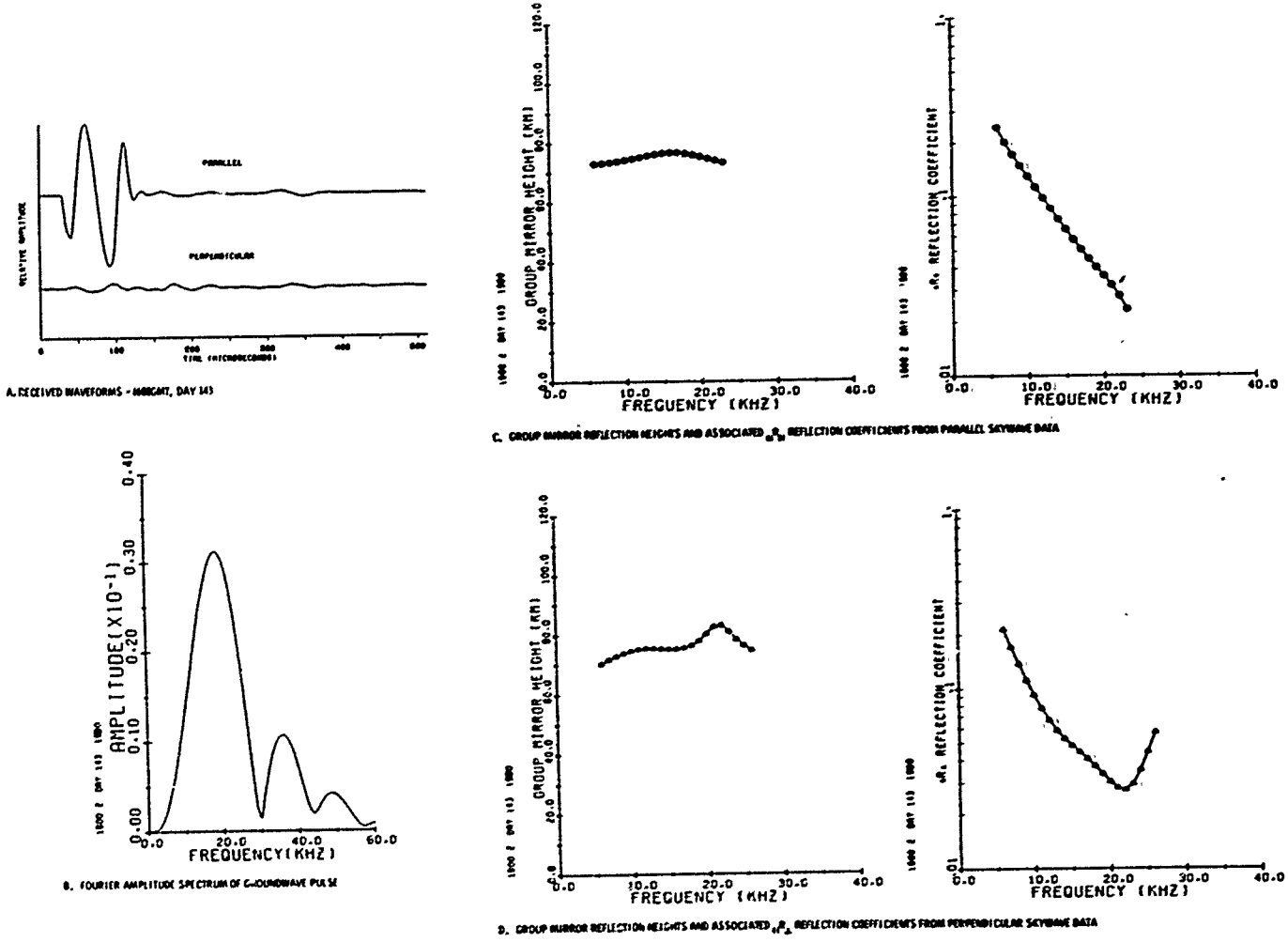
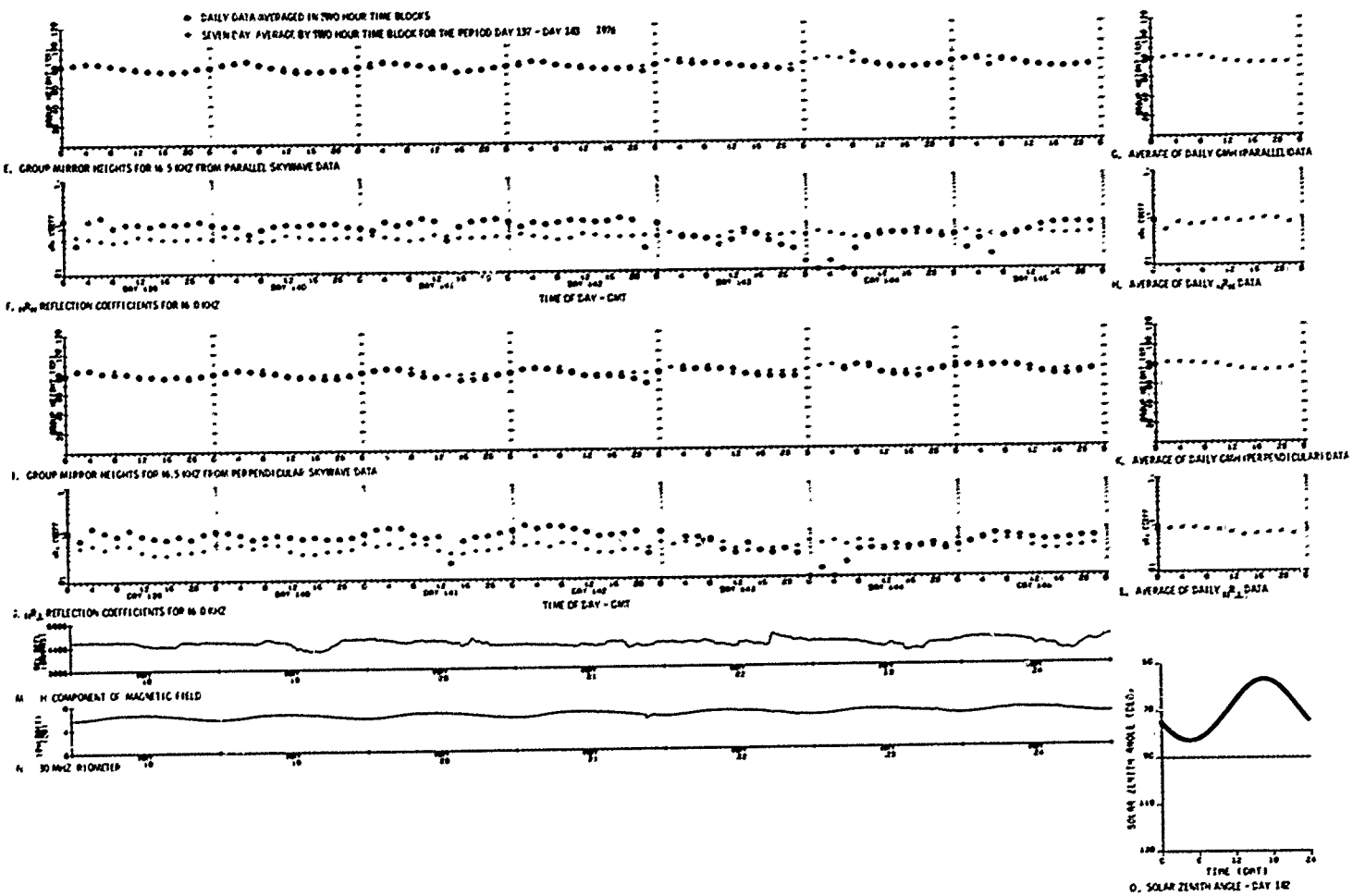


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 139 (18 May) — DAY 145 (24 May) 1980



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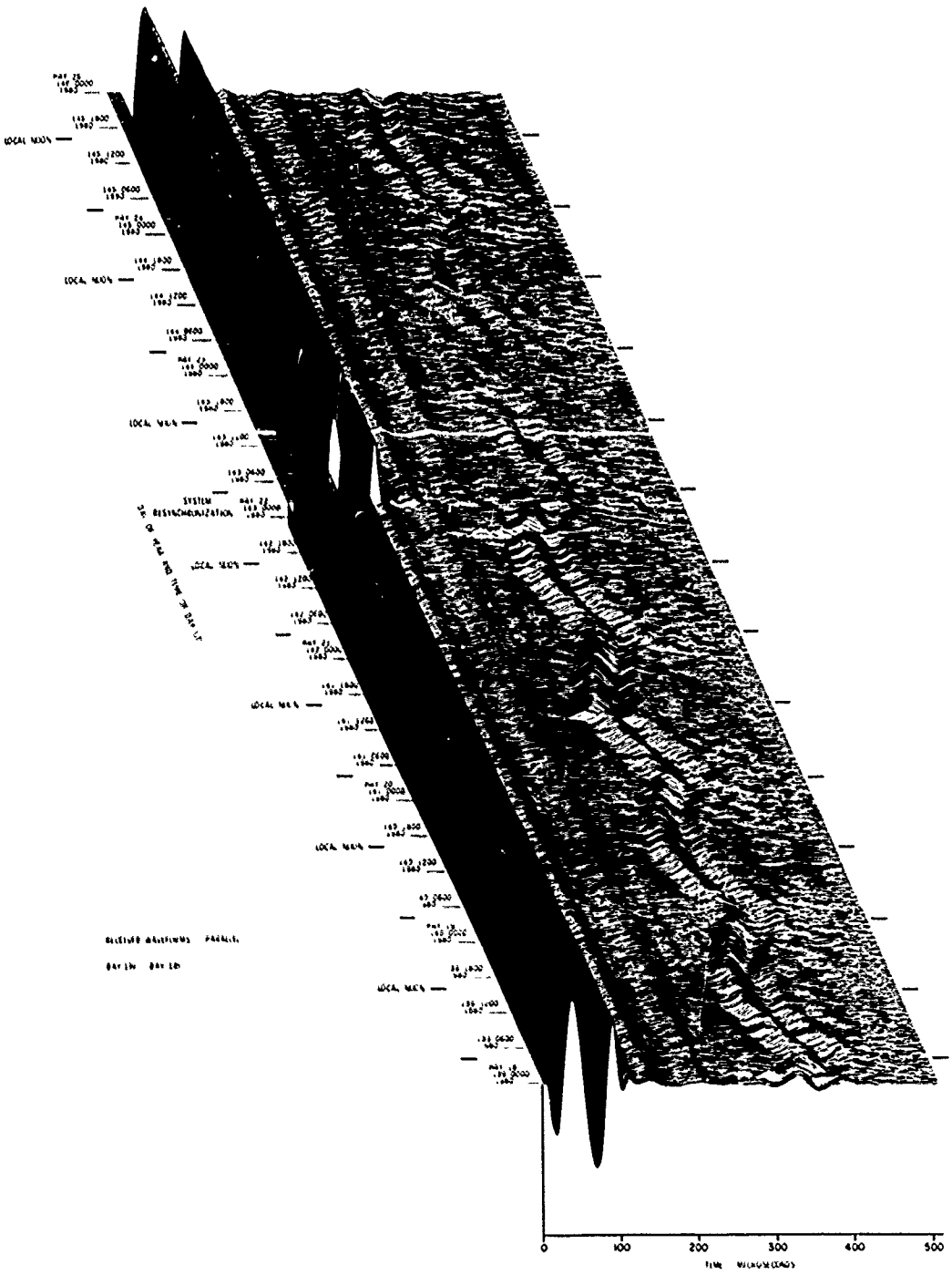

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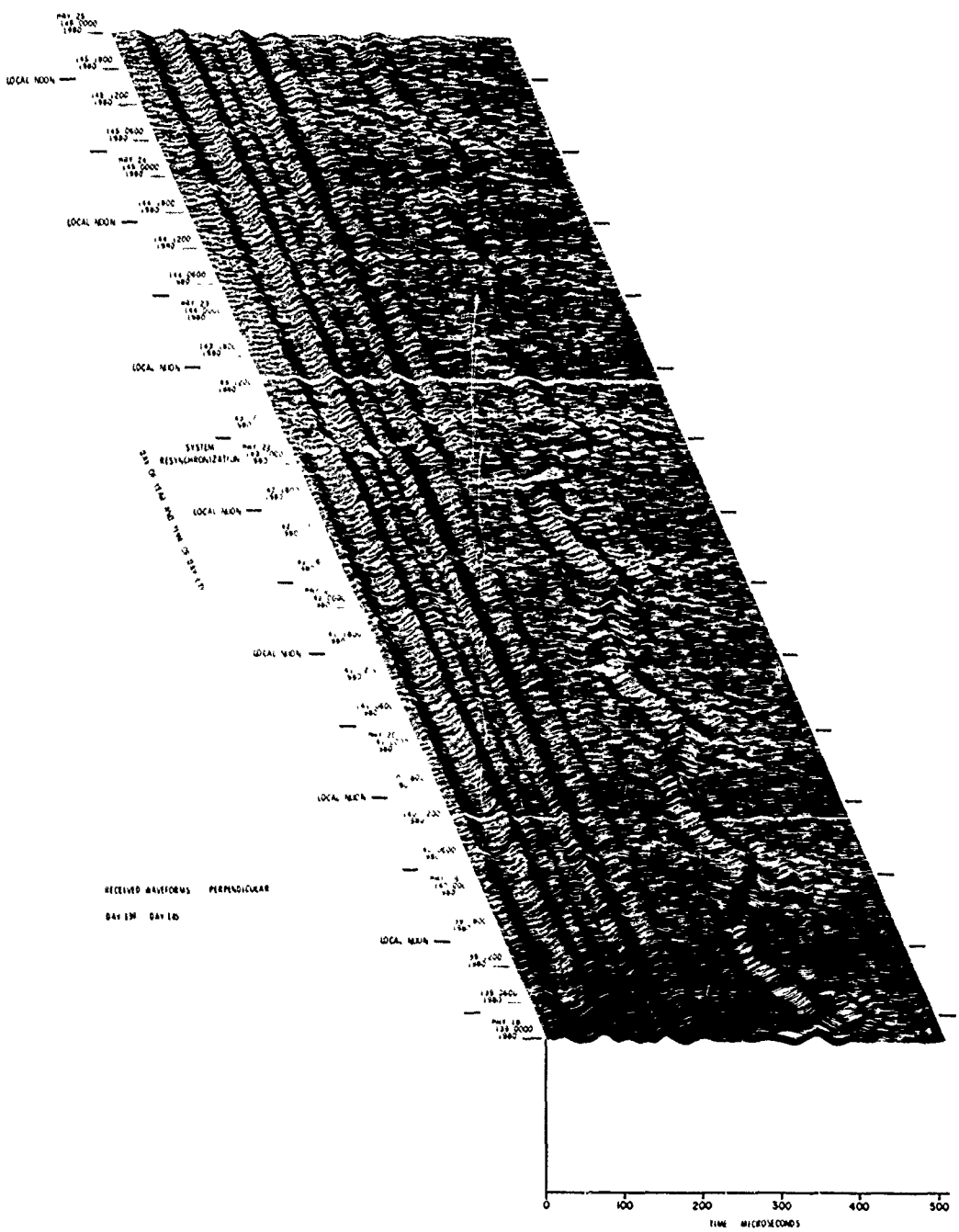


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 139 (18 May) – DAY 145 (24 May) 1980 (Cont)
Part S. ⊥ Waveform Display

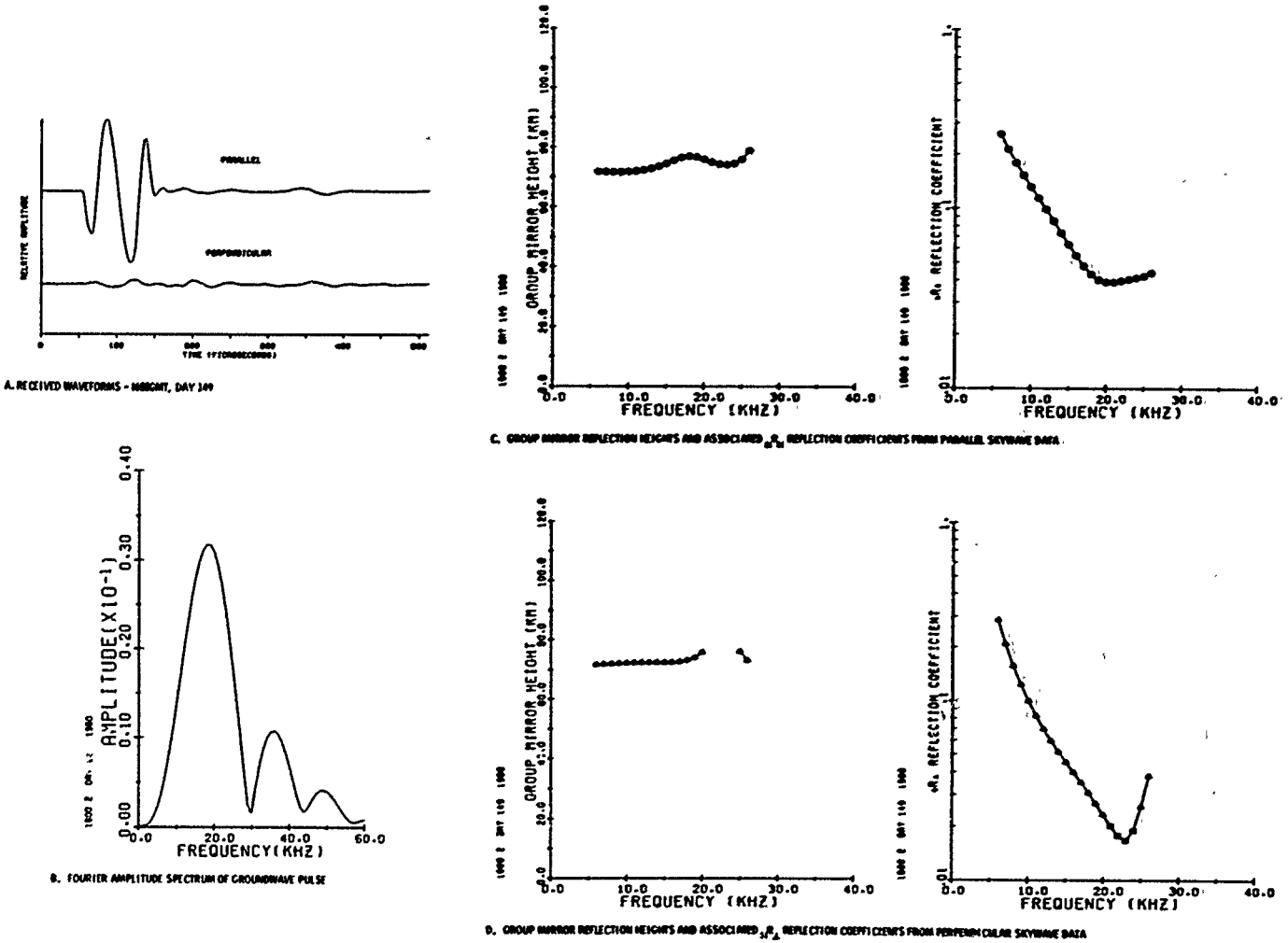
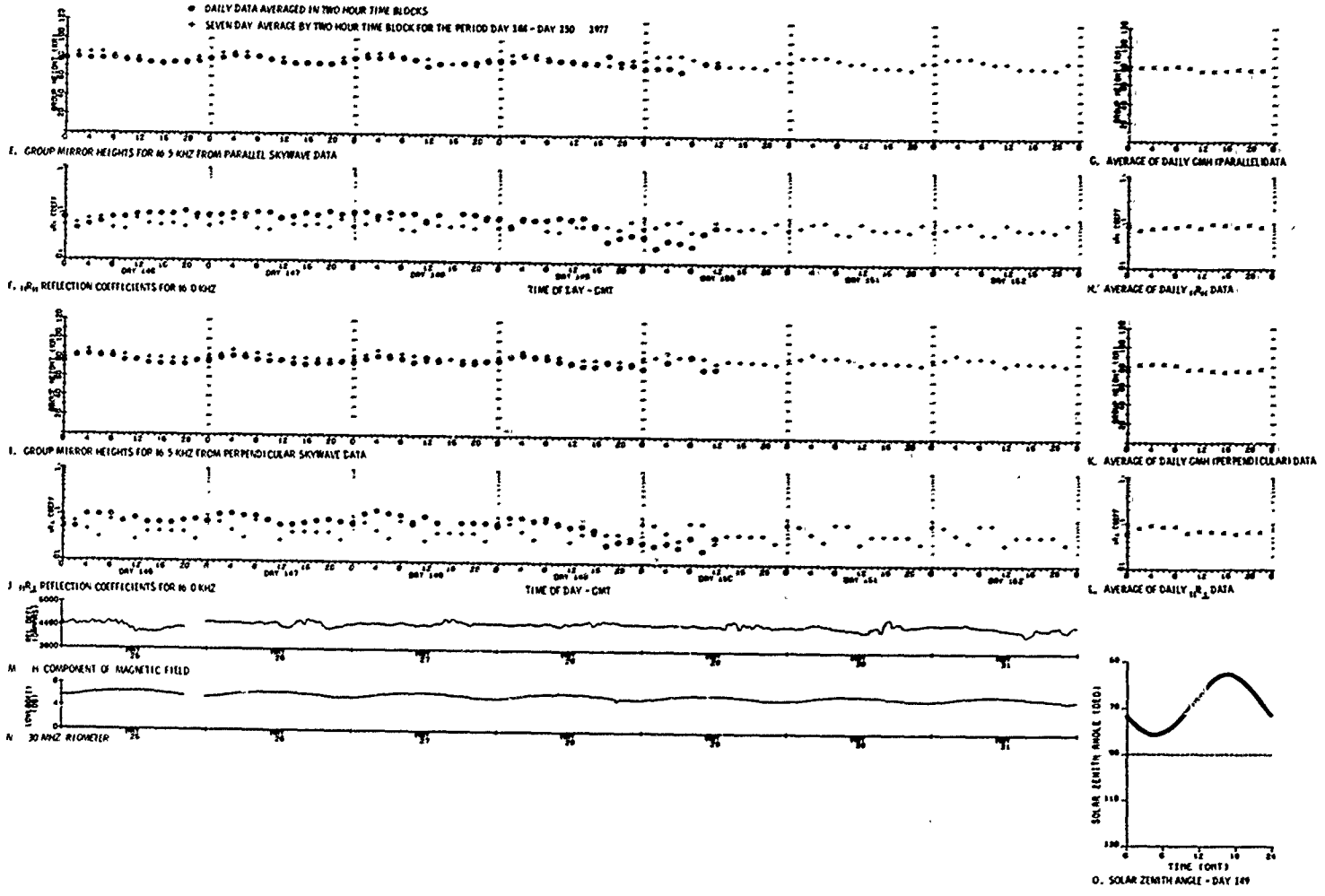


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 146 (25 May) — DAY 152 (31 May) 1980



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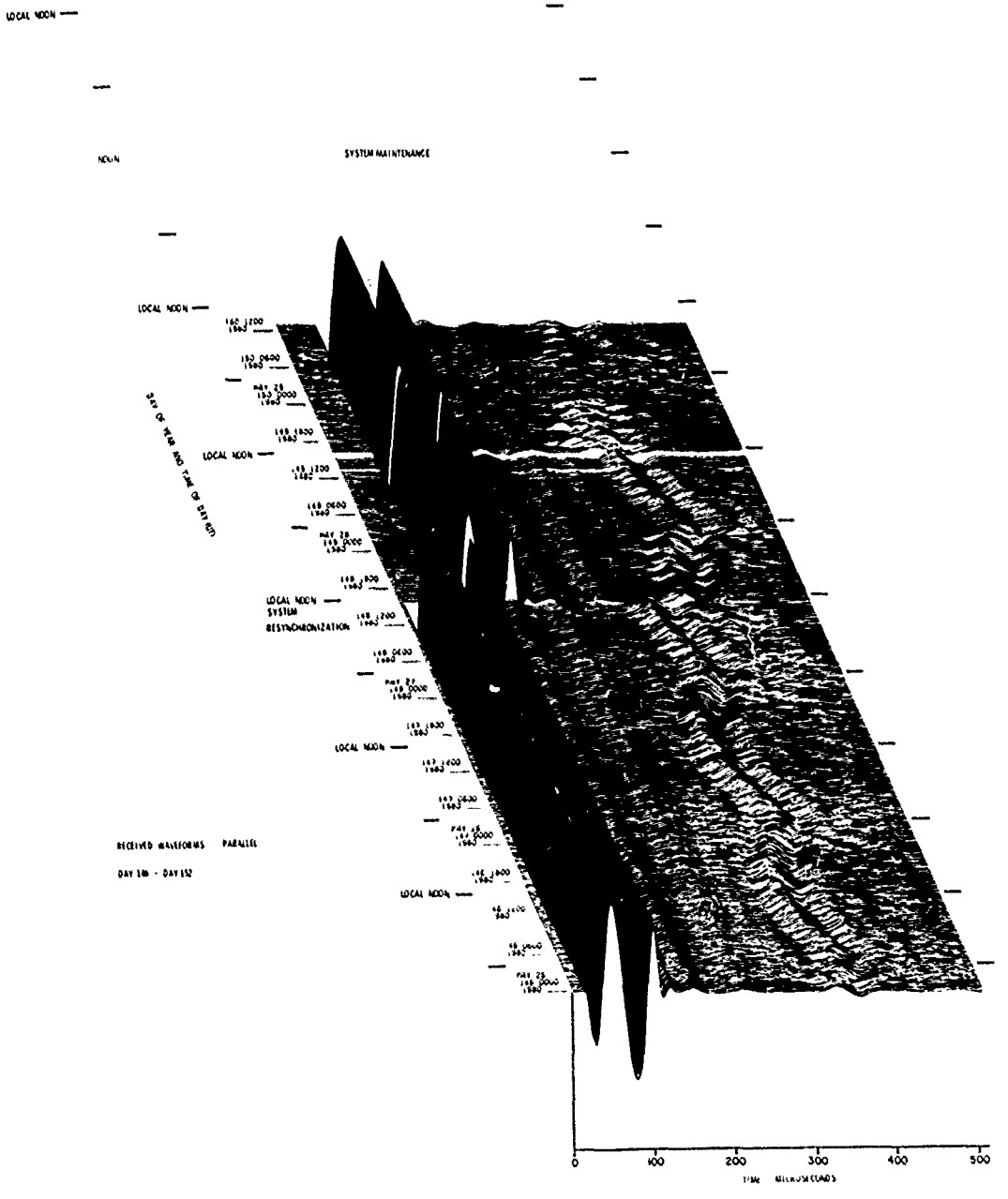

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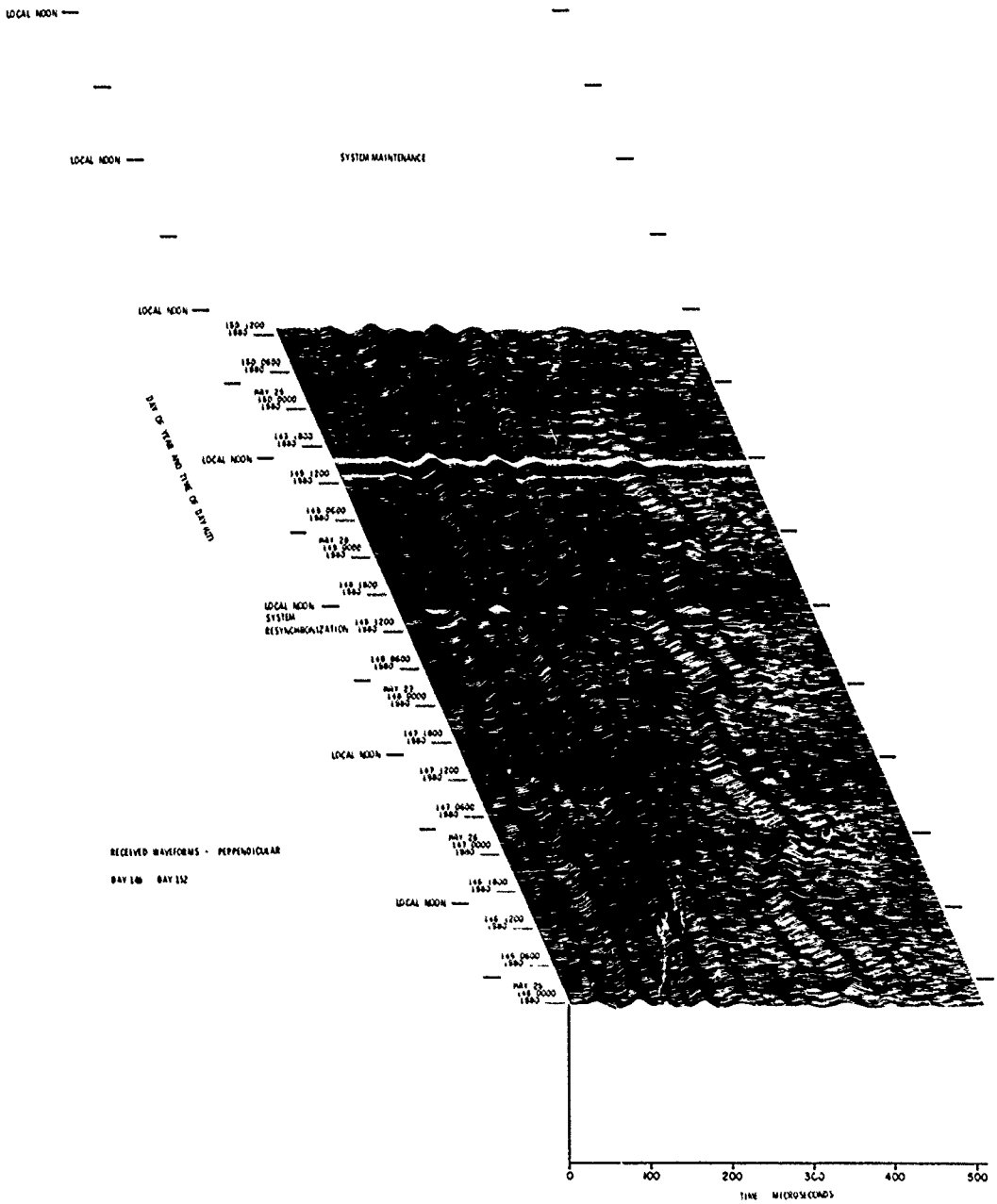

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Part S. ⊥ Waveform Display

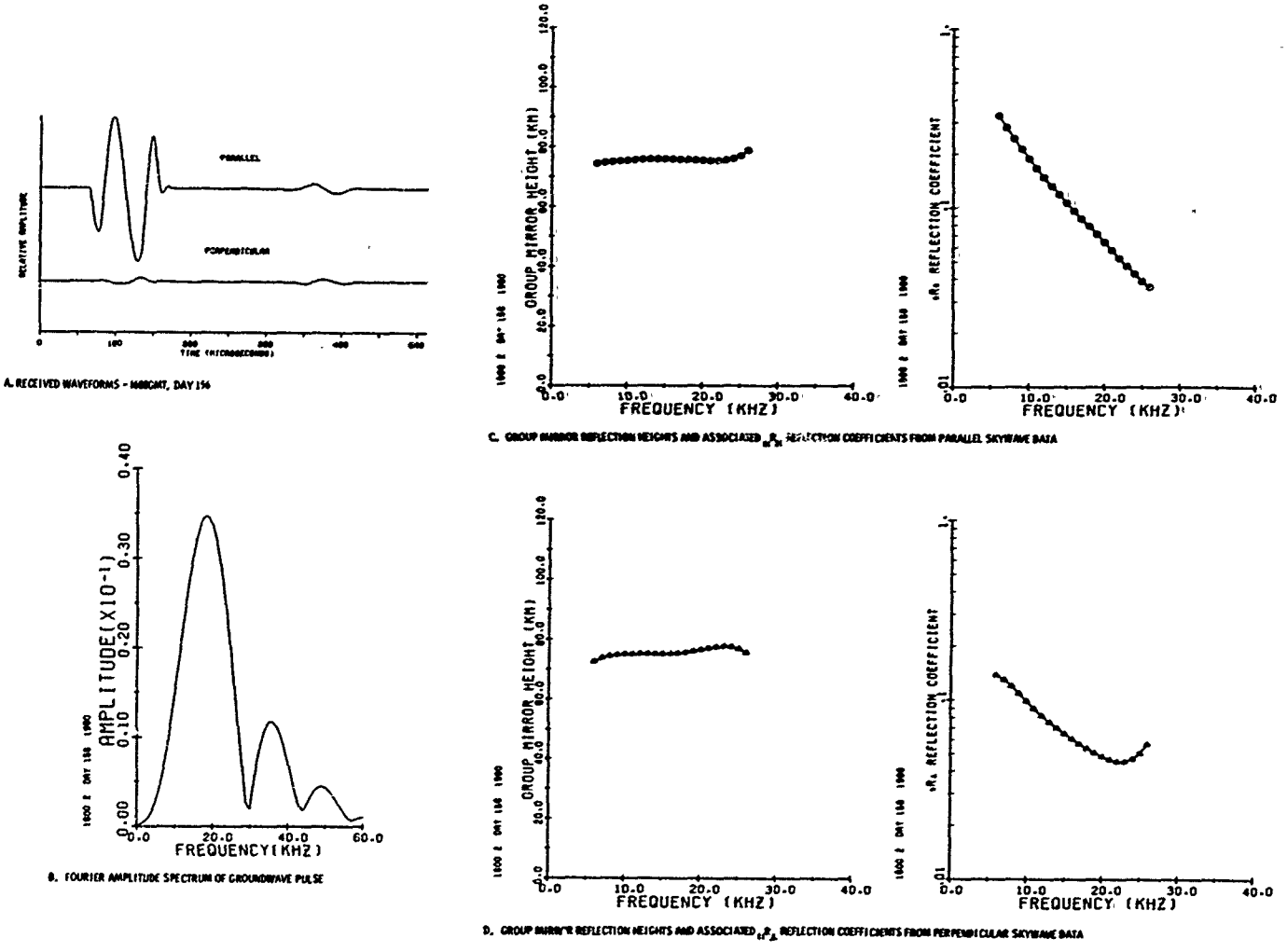
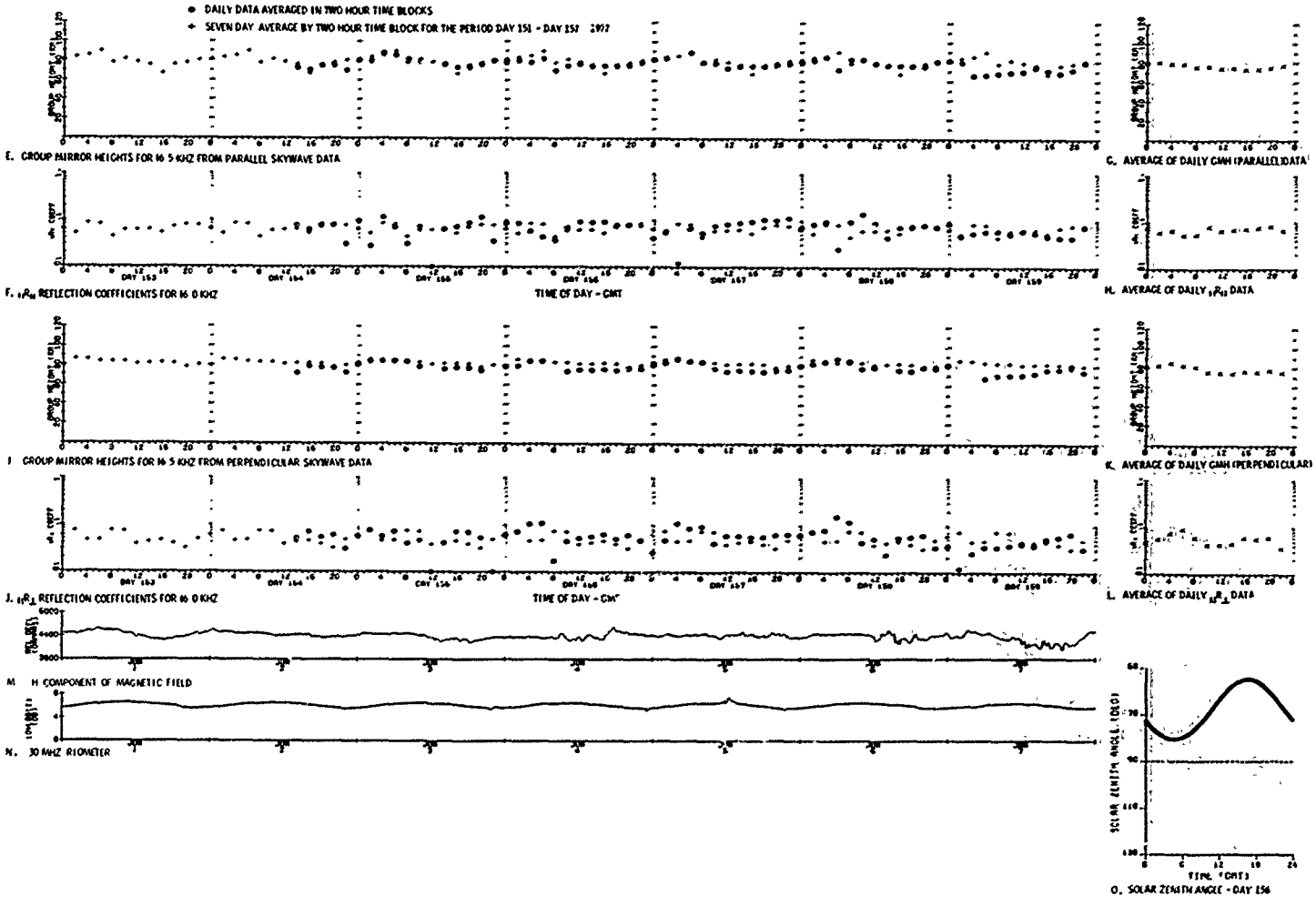


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 153 (1 Jun) — DAY 159 (7 Jun) 1980



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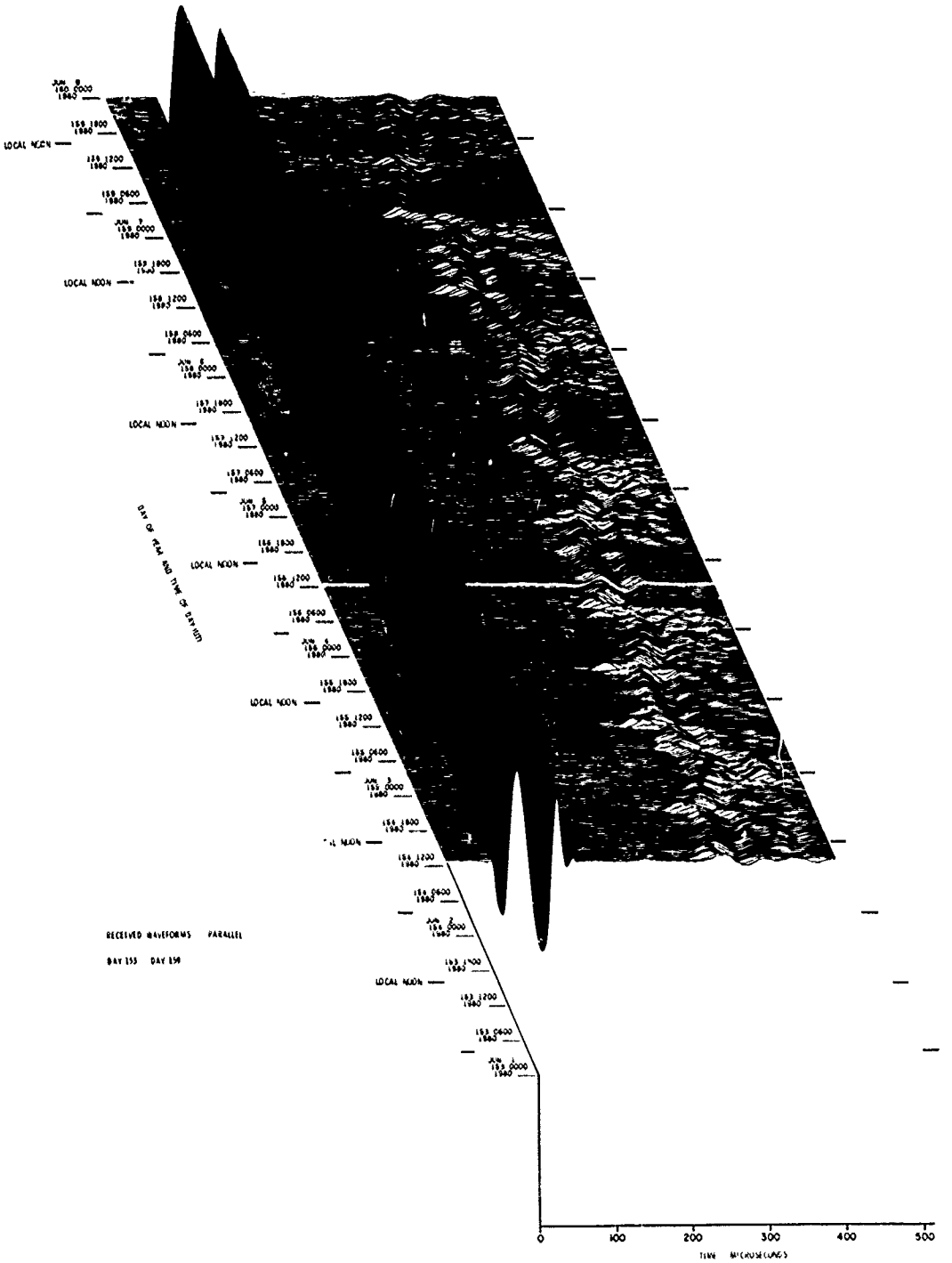

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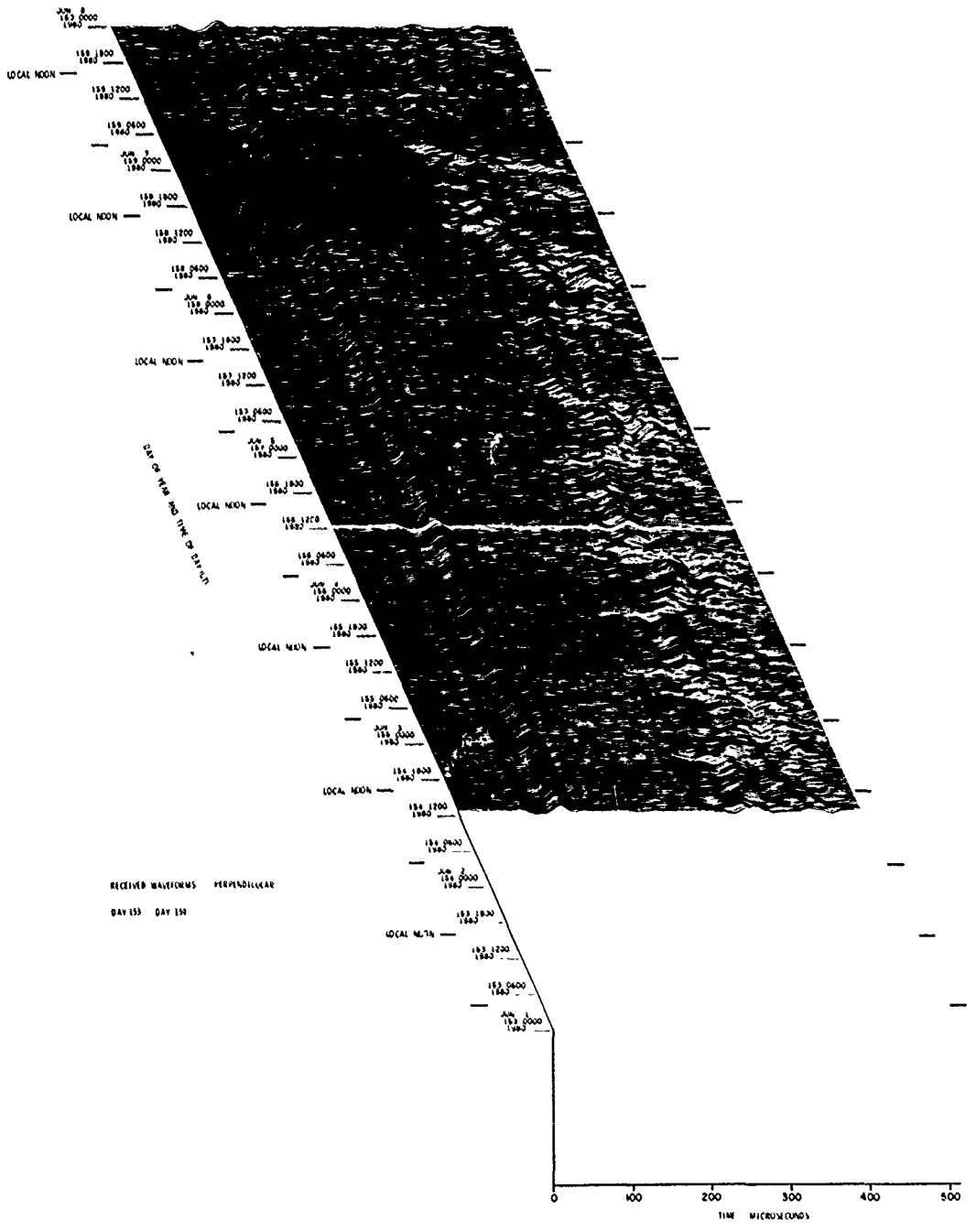

Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 153 (1 Jun) – DAY 159 (7 Jun) 1980 (Cont)
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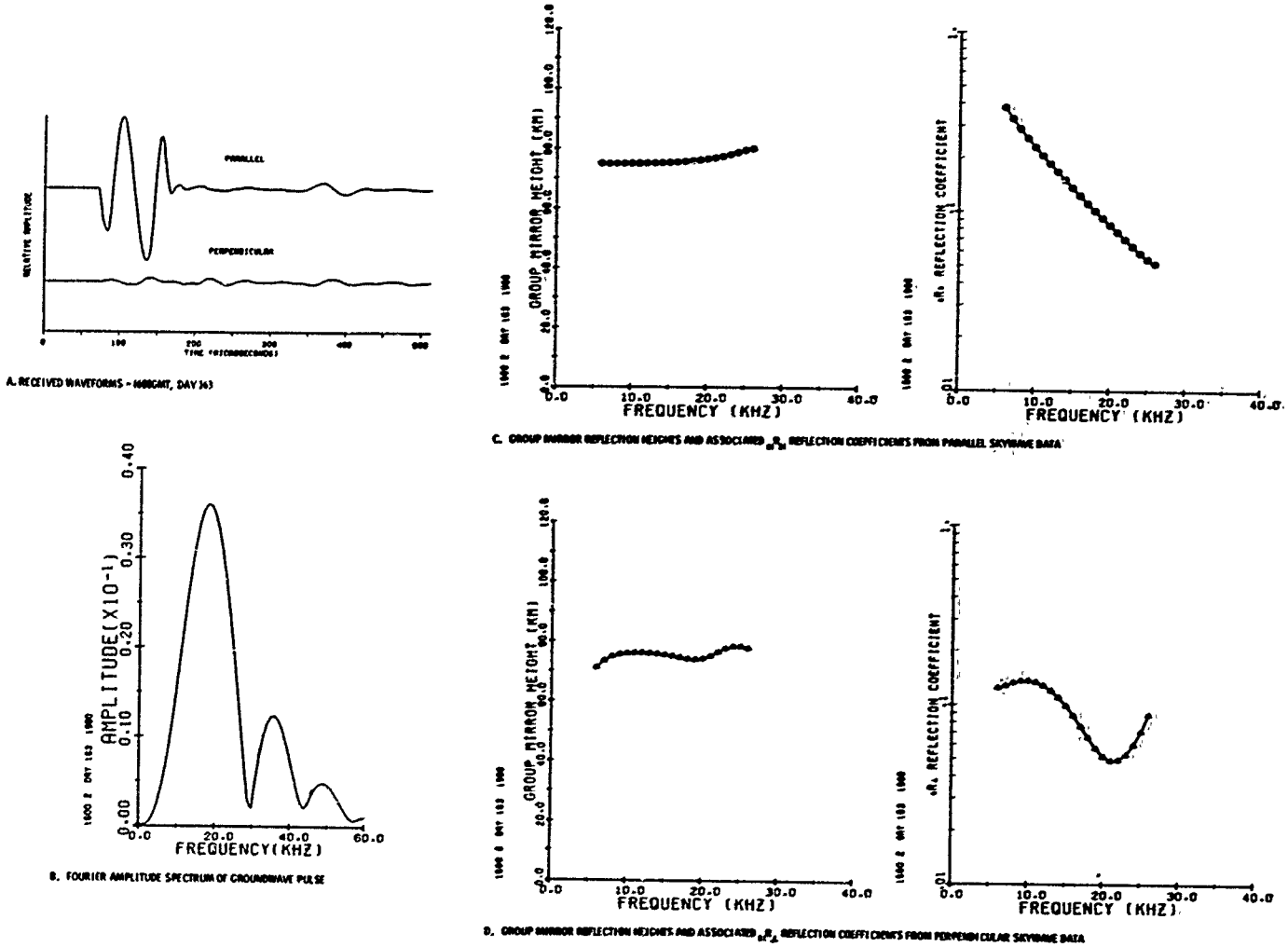
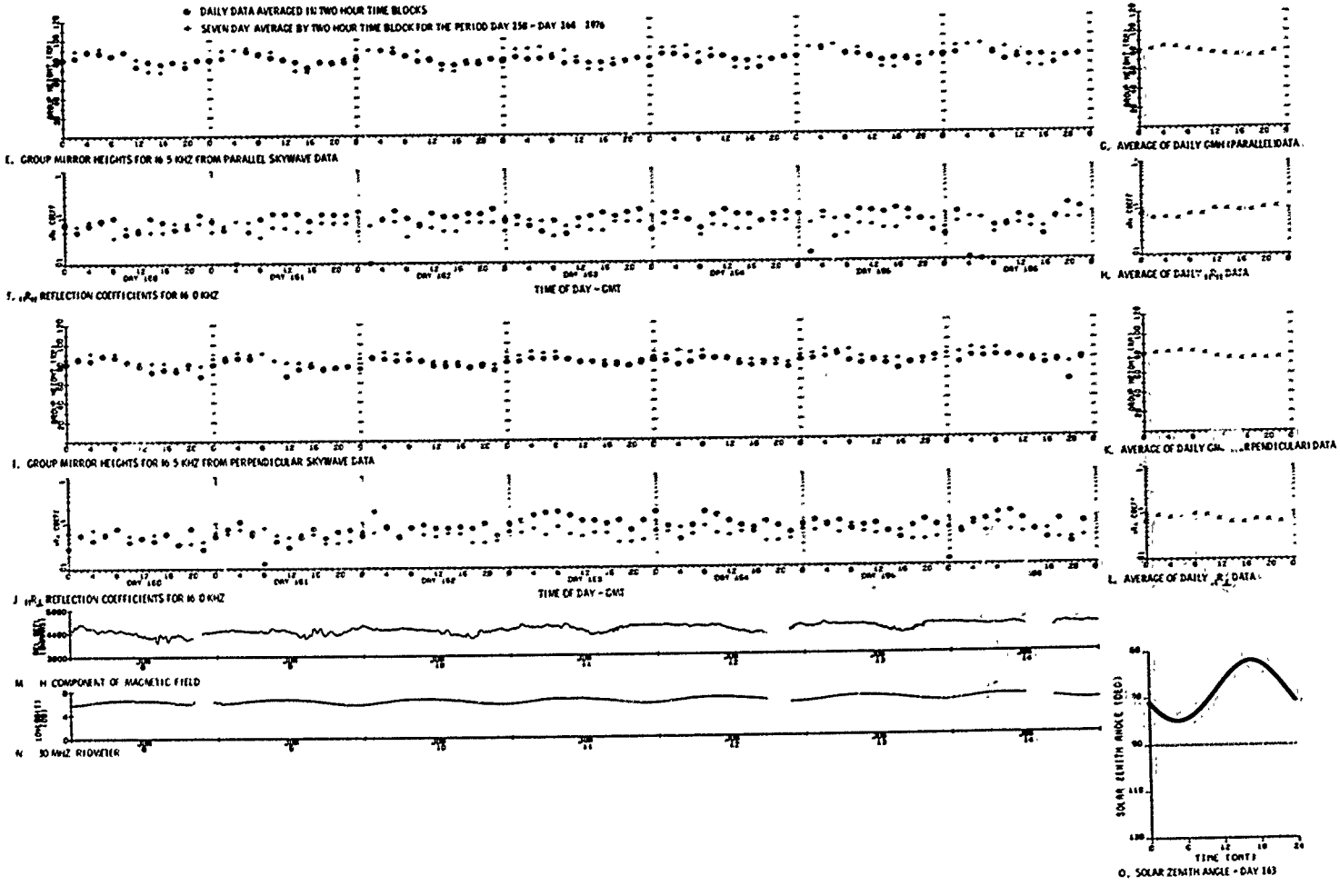


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 160 (8 Jun) – DAY 166 (14 Jun) 1980



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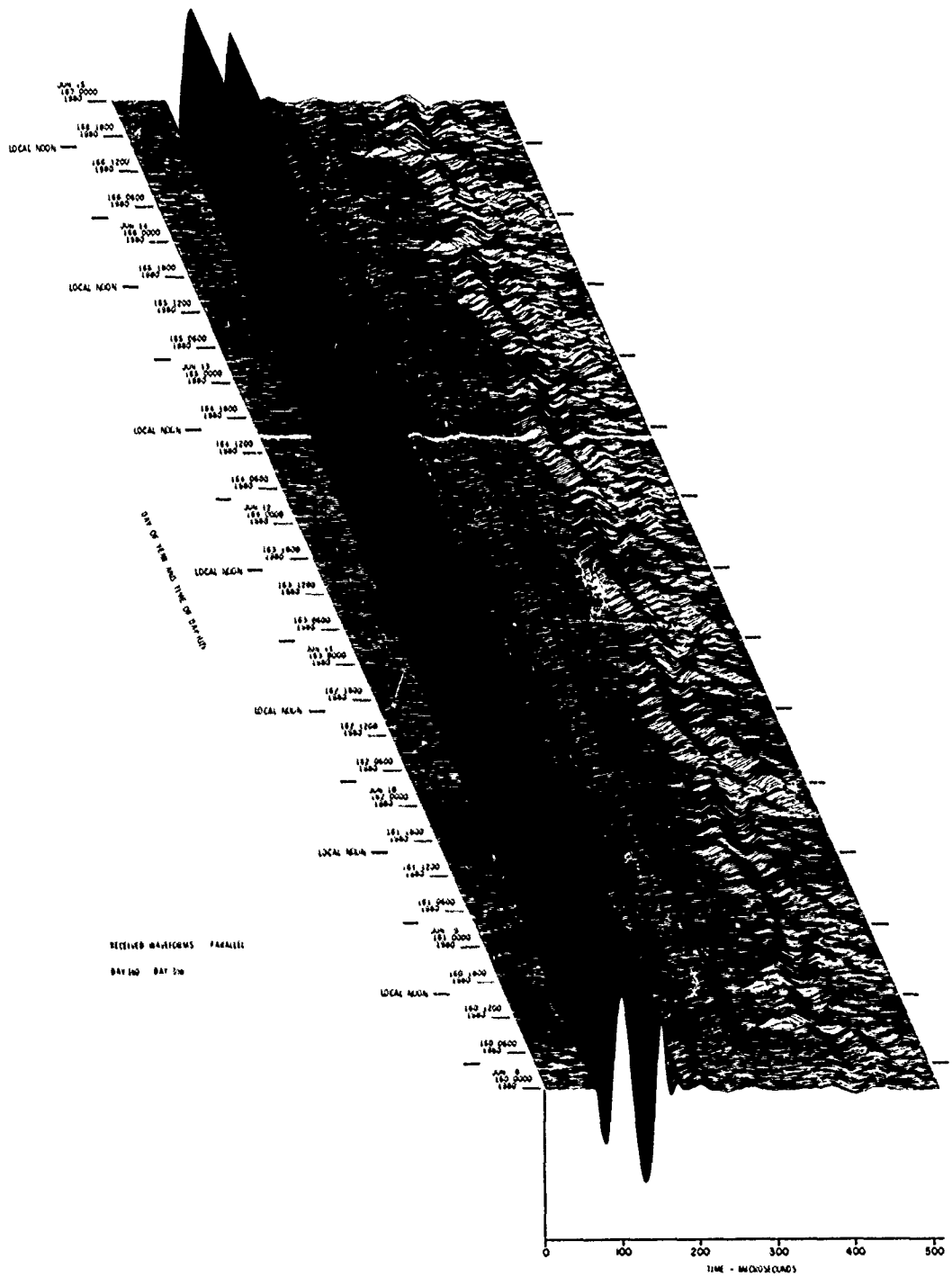

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Part R. || Waveform Display

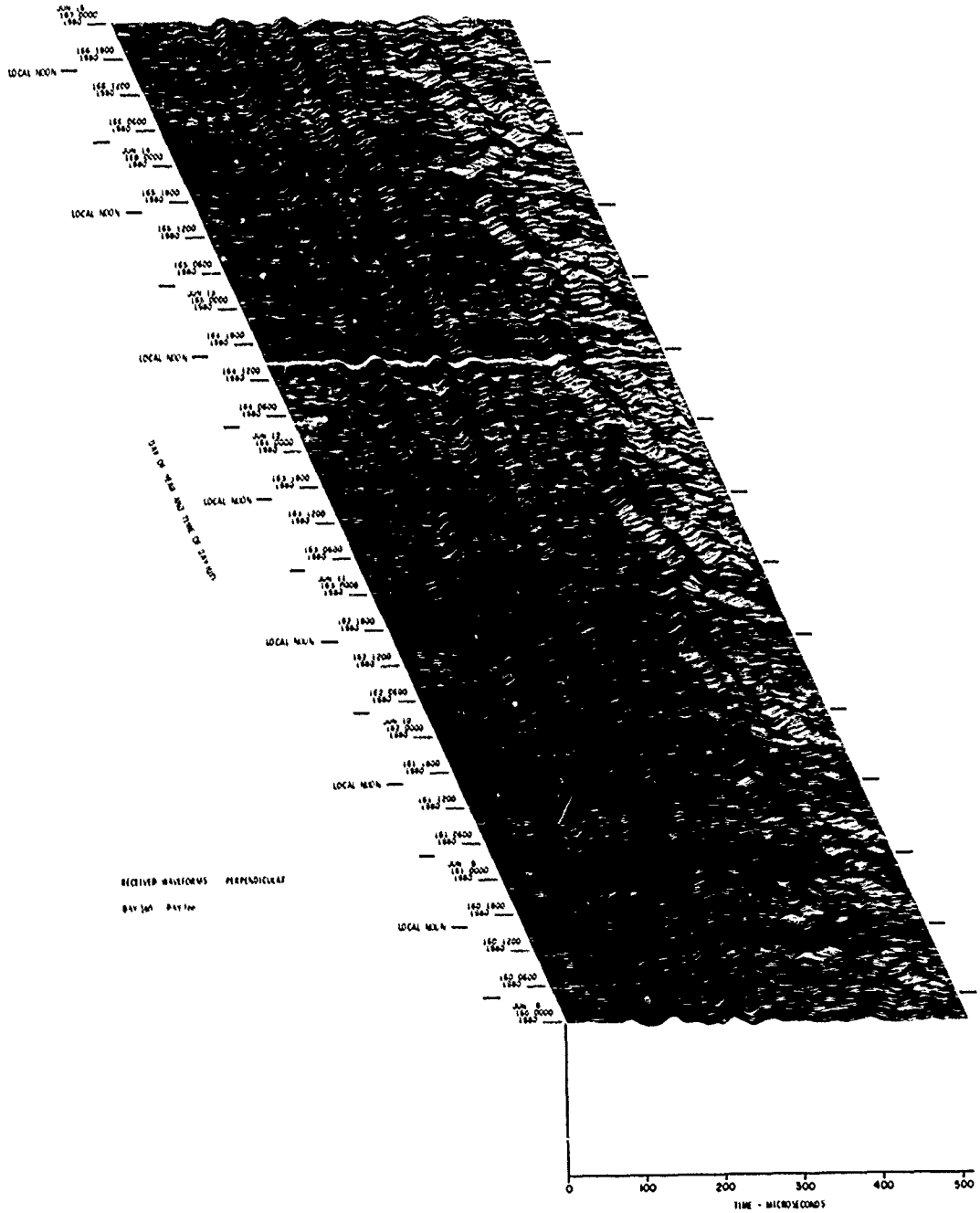

Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 160 (8 Jun) – DAY 166 (14 Jun) 1980 (Cont)
Part S. ⊥ Waveform Display

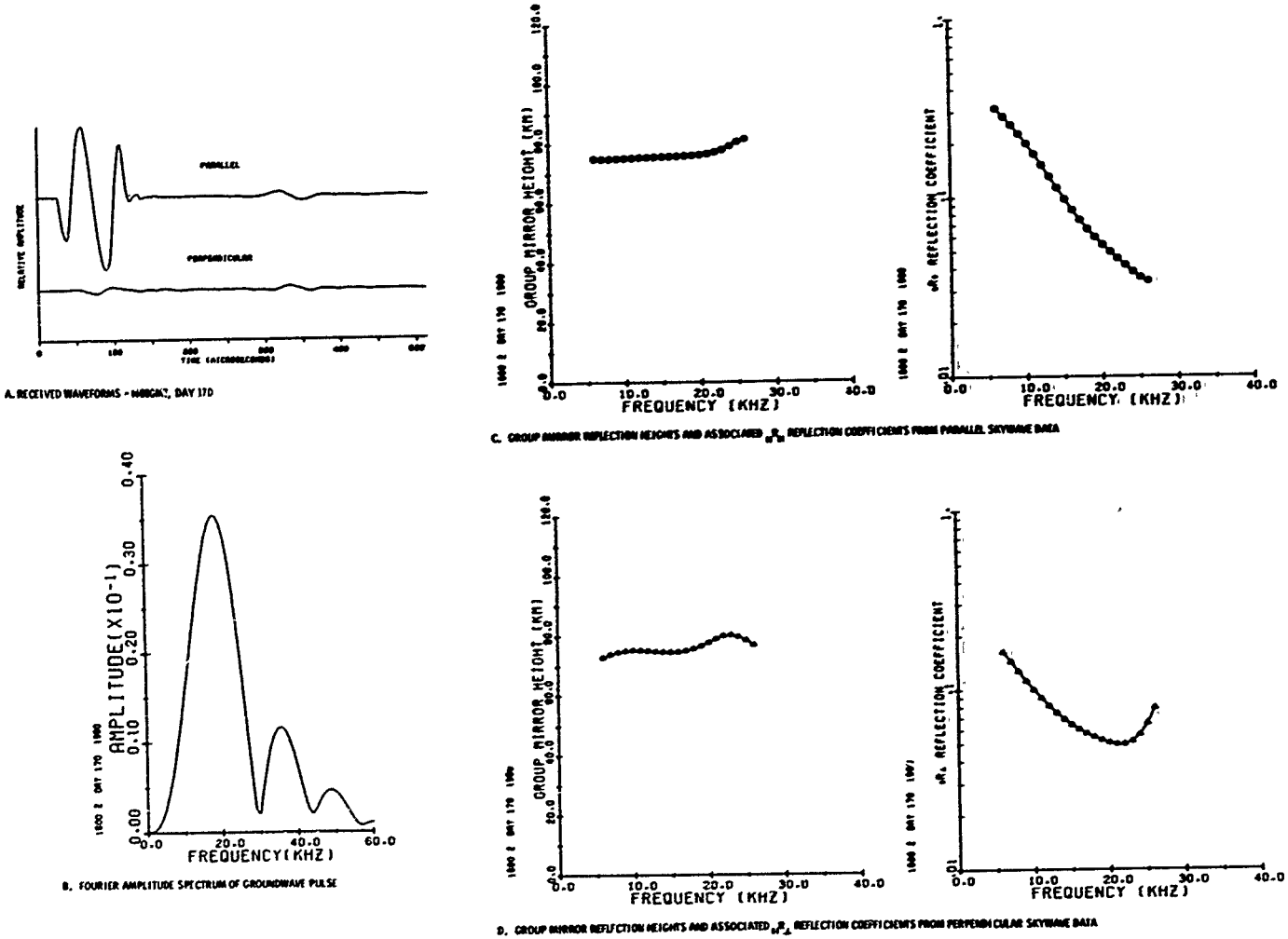

Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 167 (15 Jun) — DAY 173 (21 Jun) 1980

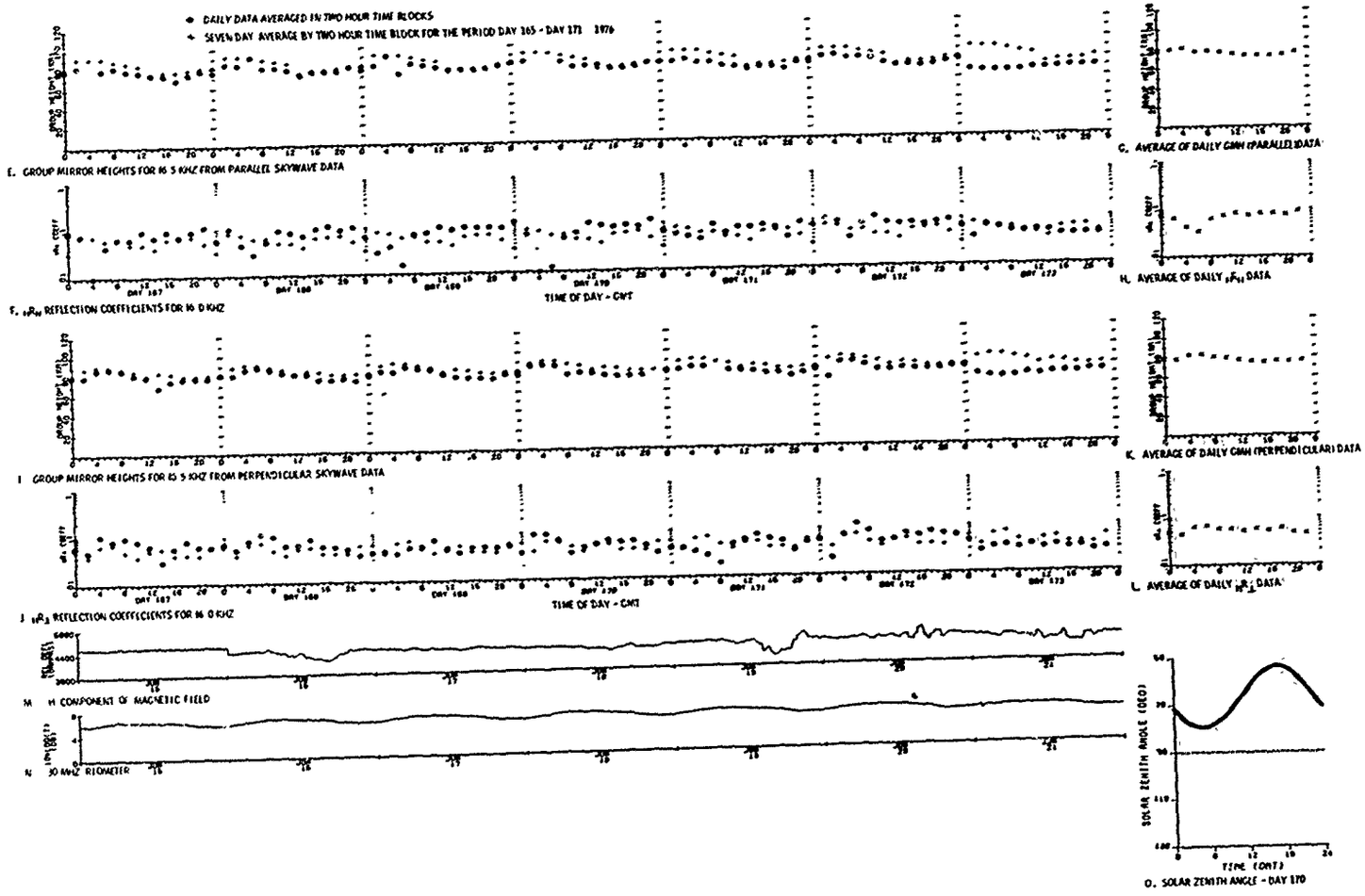

Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 167 (15 Jun) — DAY 173 (21 Jun) 1980 (Cont)

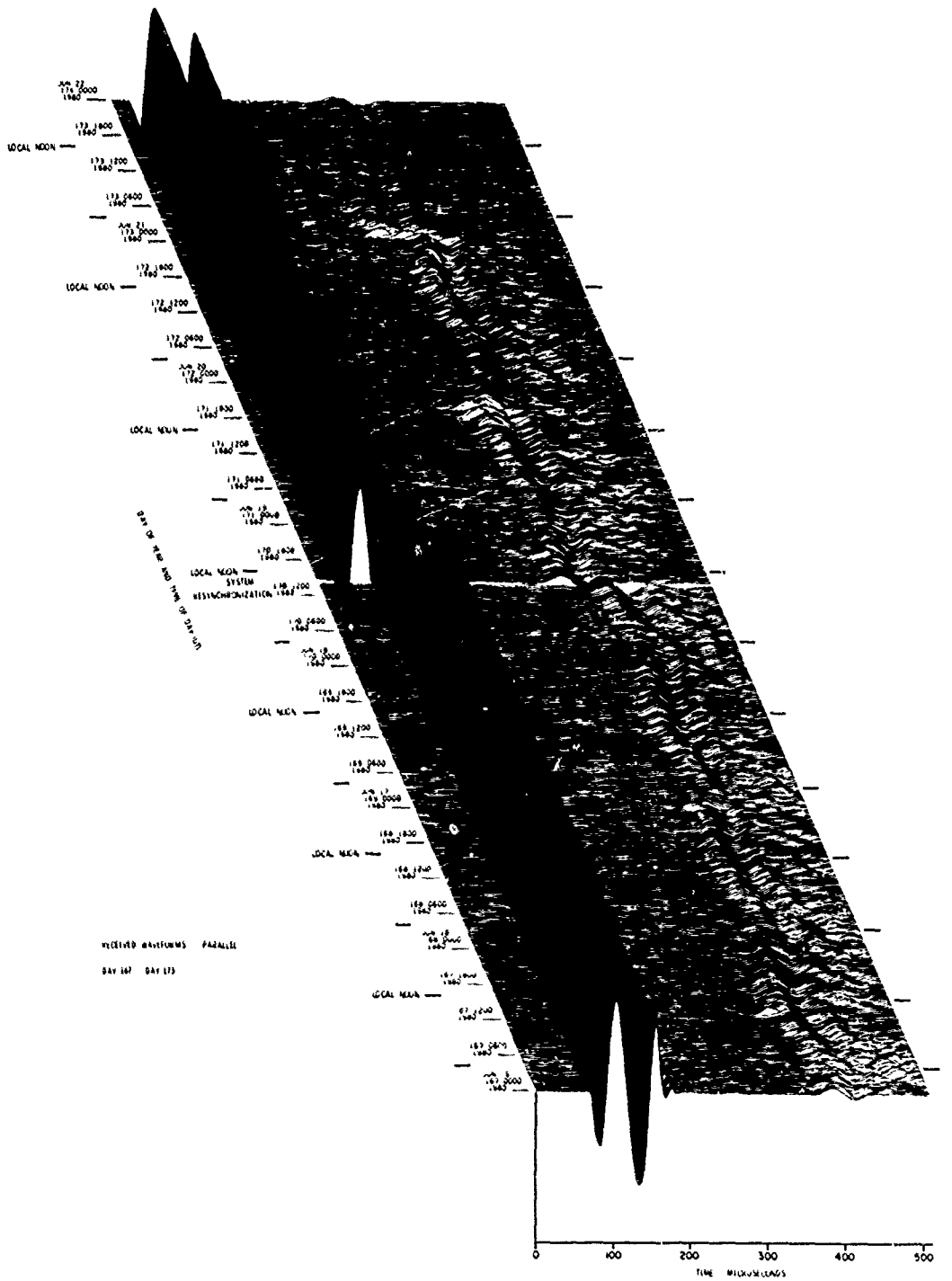

Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 167 (15 Jun) – DAY 173 (21 Jun) 1980 (Cont)
Part R. || Waveform Display

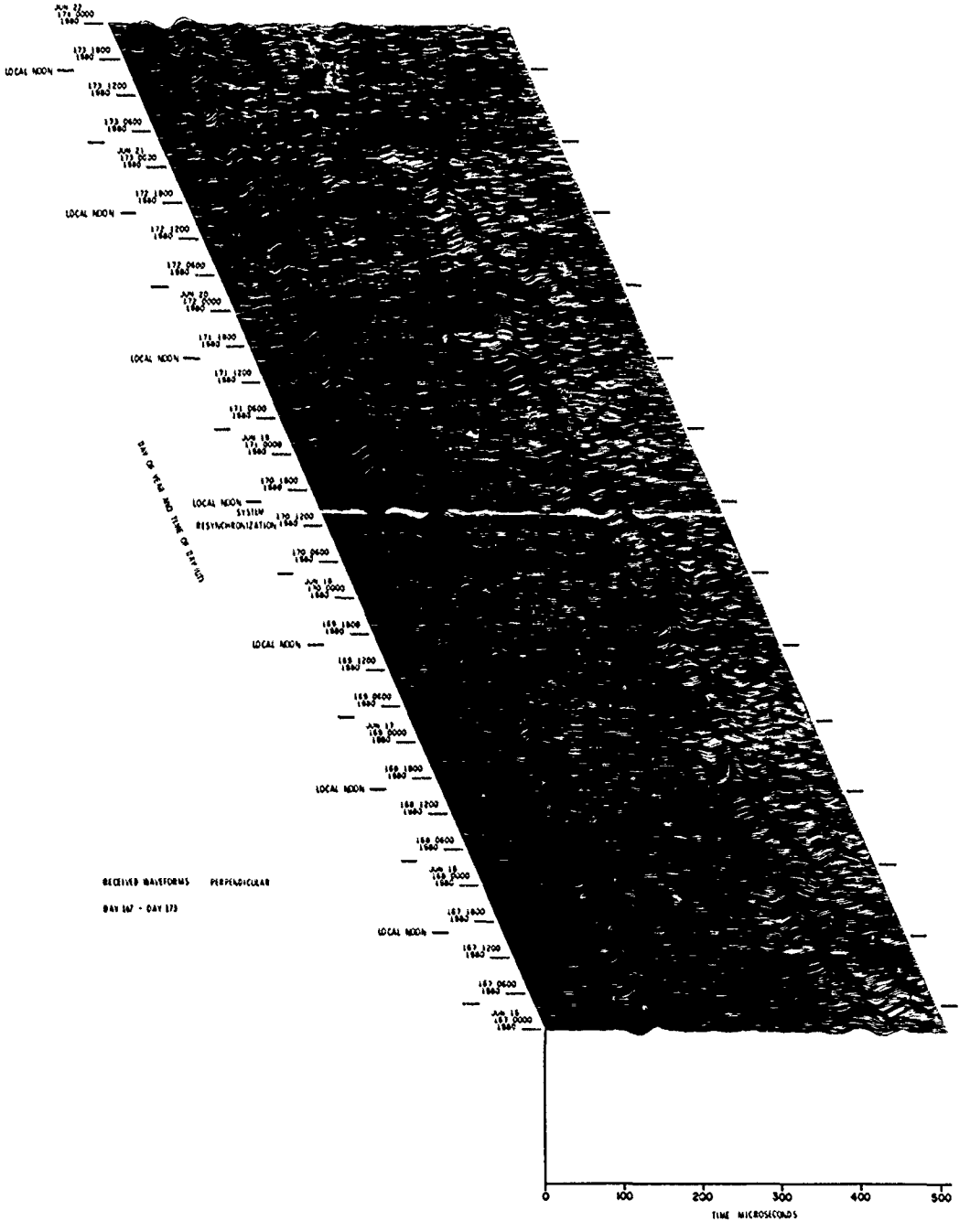

Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 167 (15 Jun) – DAY 173 (21 Jun) 1980 (Cont)
Part S. ⊥ Waveform Display

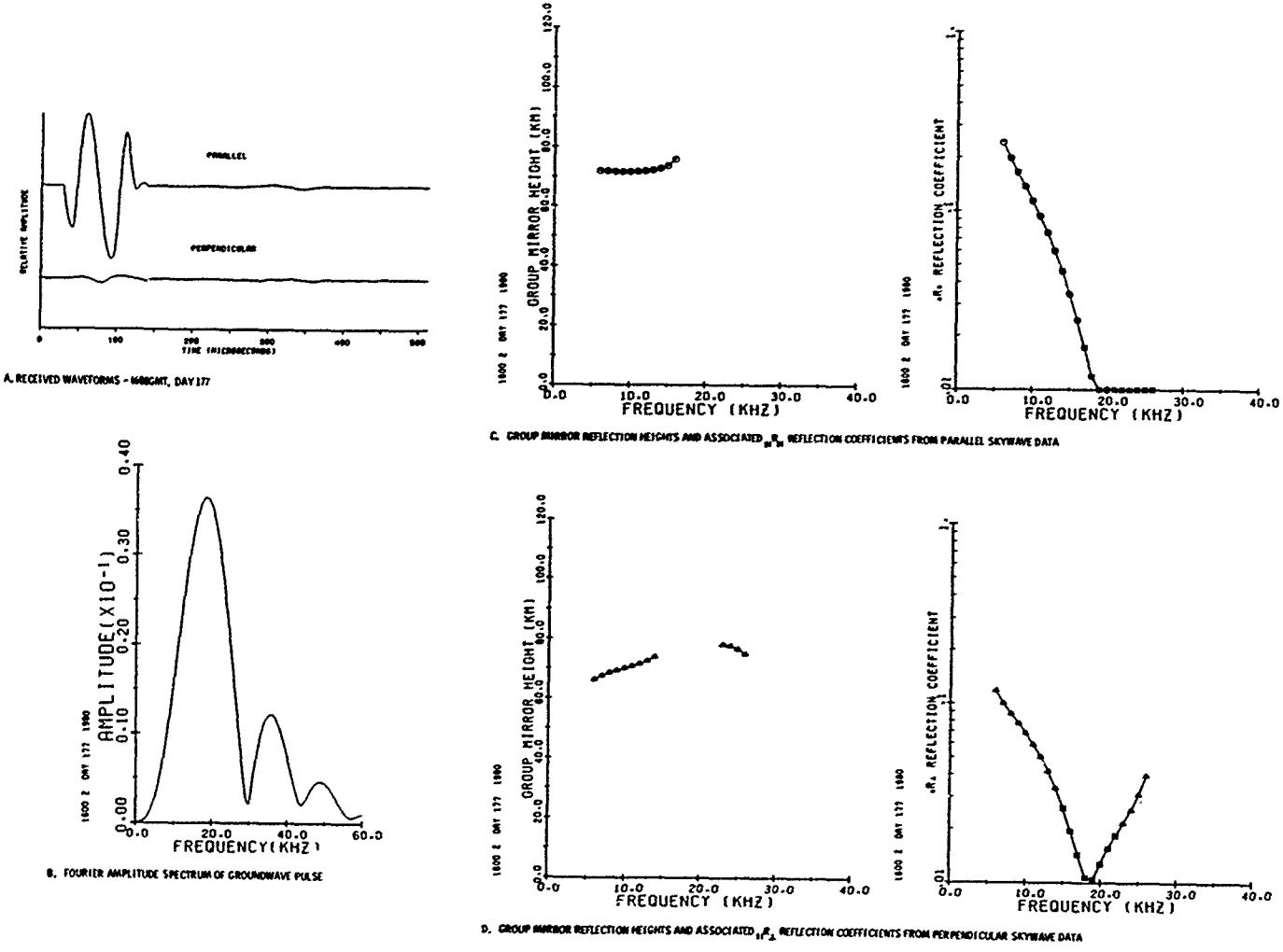

Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 174 (22 Jun) — DAY 180 (28 Jun) 1980

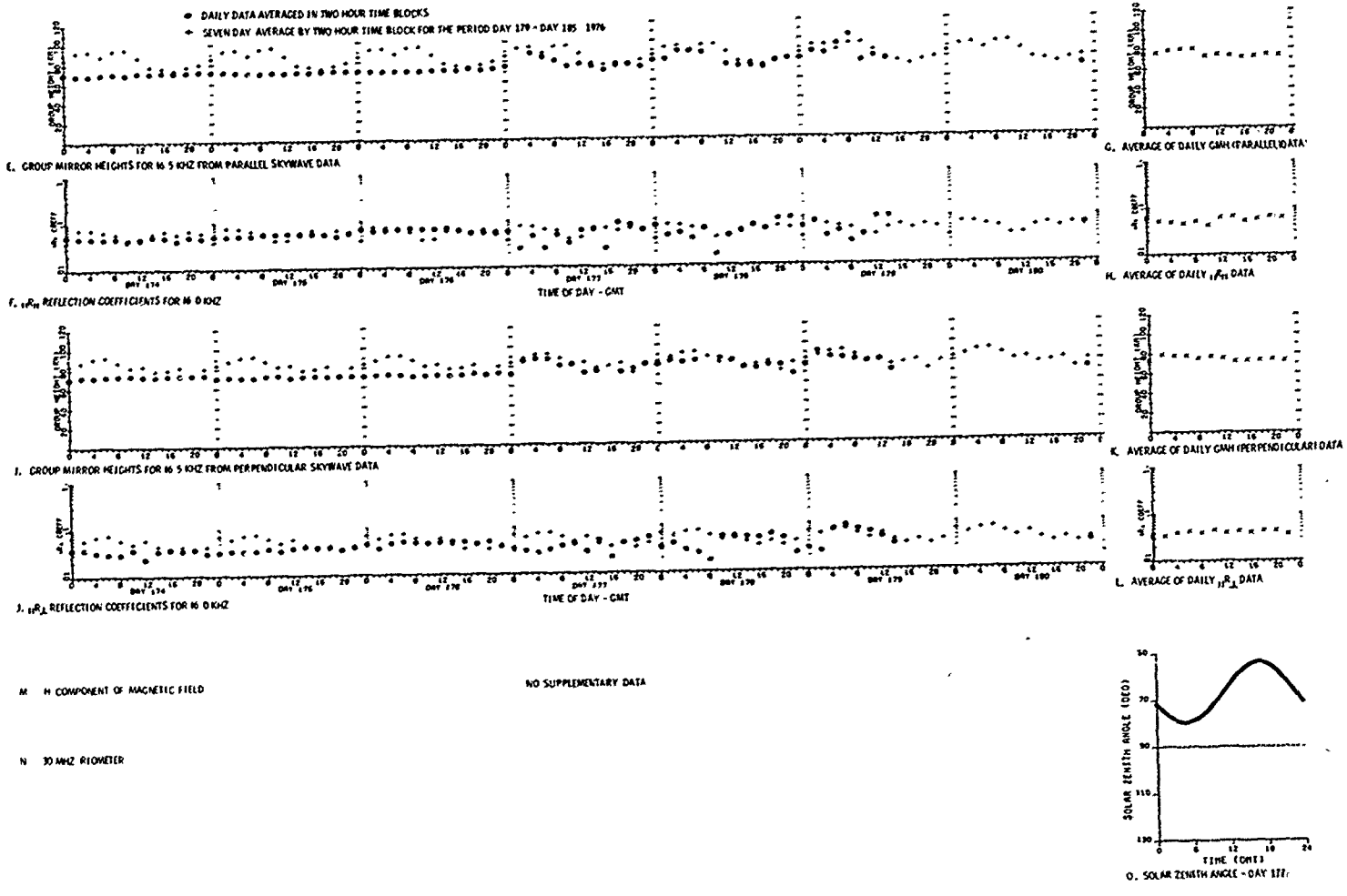

Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 174 (22 Jun) — DAY 180 (28 Jun) 1980 (Cont)

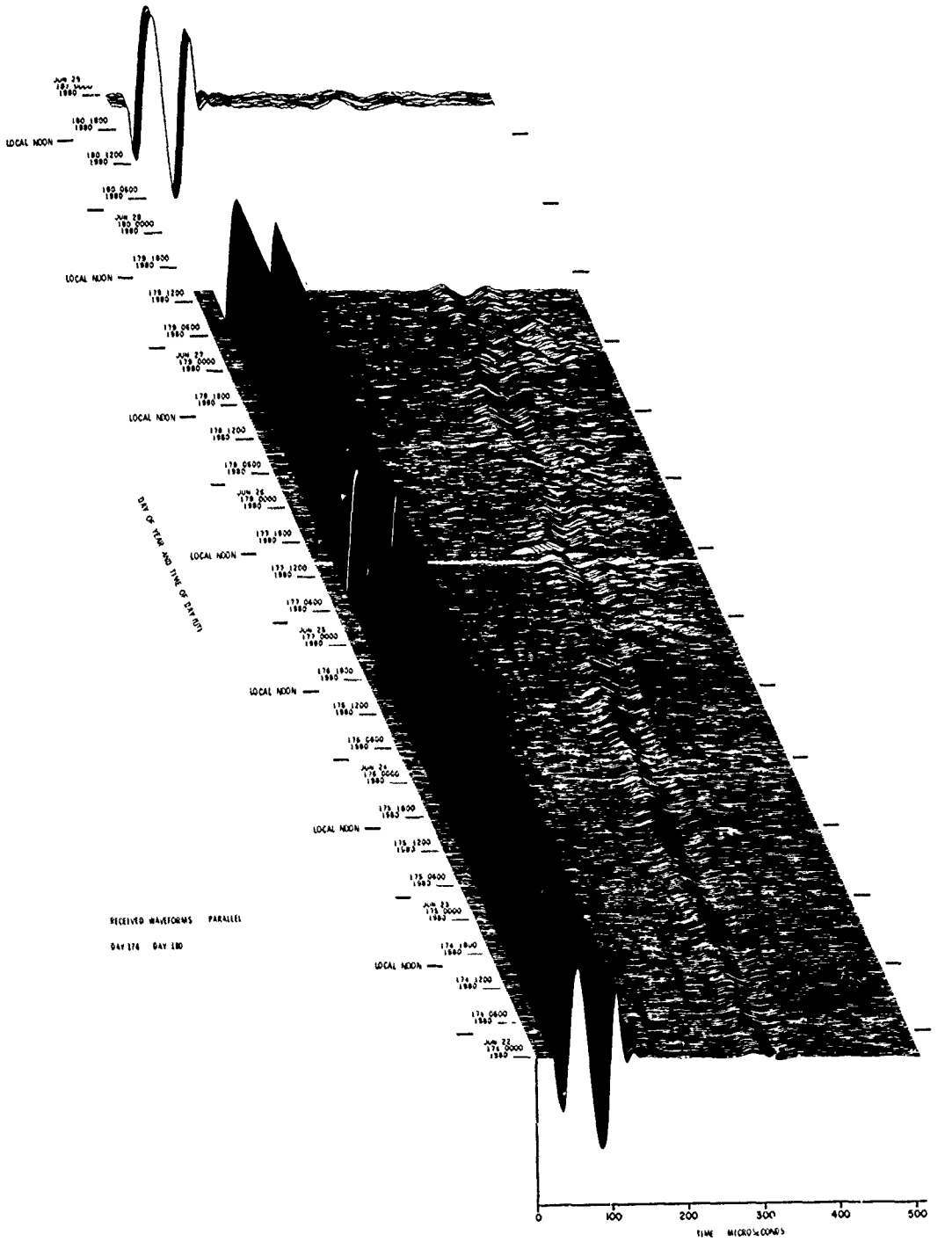

Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 174 (22 Jun) – DAY 180 (28 Jun) 1980 (Cont)
Part R. ||Waveform Display

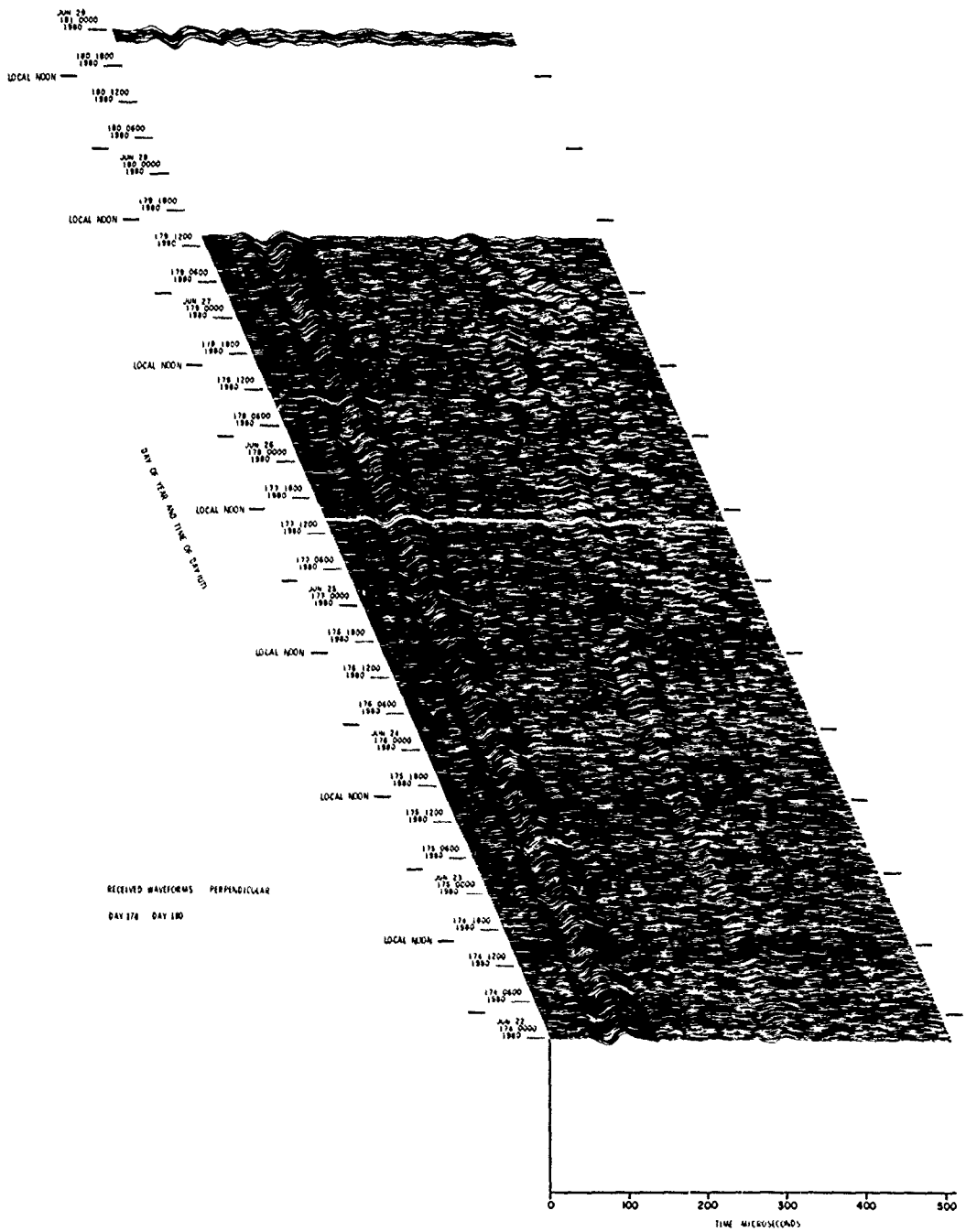

Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 174 (22 Jun) – DAY 180 (28 Jun) 1980 (Cont)
Part S. ⊥ Waveform Display

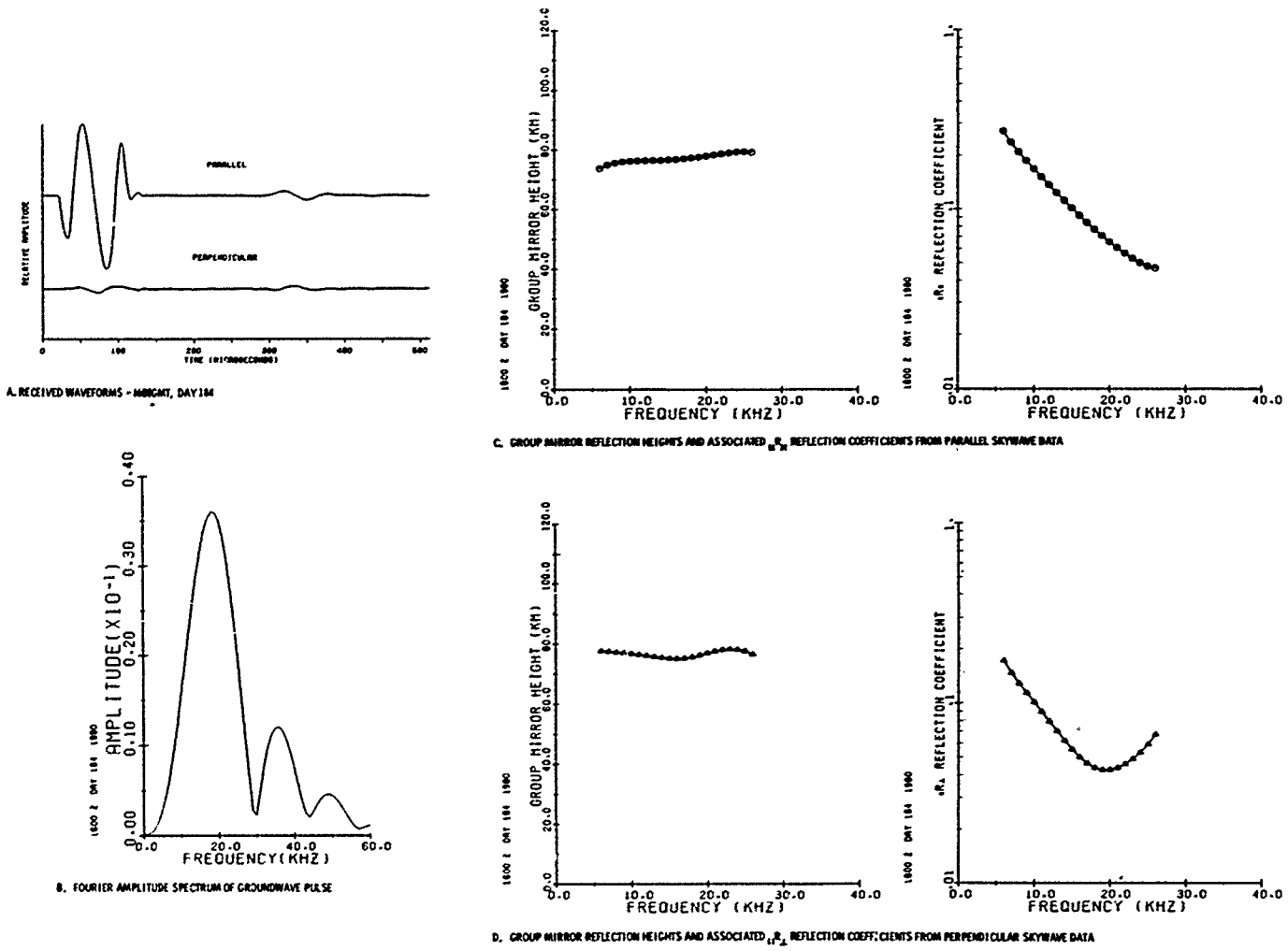

Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 181 (29 Jun) — DAY 187 (5 Jul) 1980

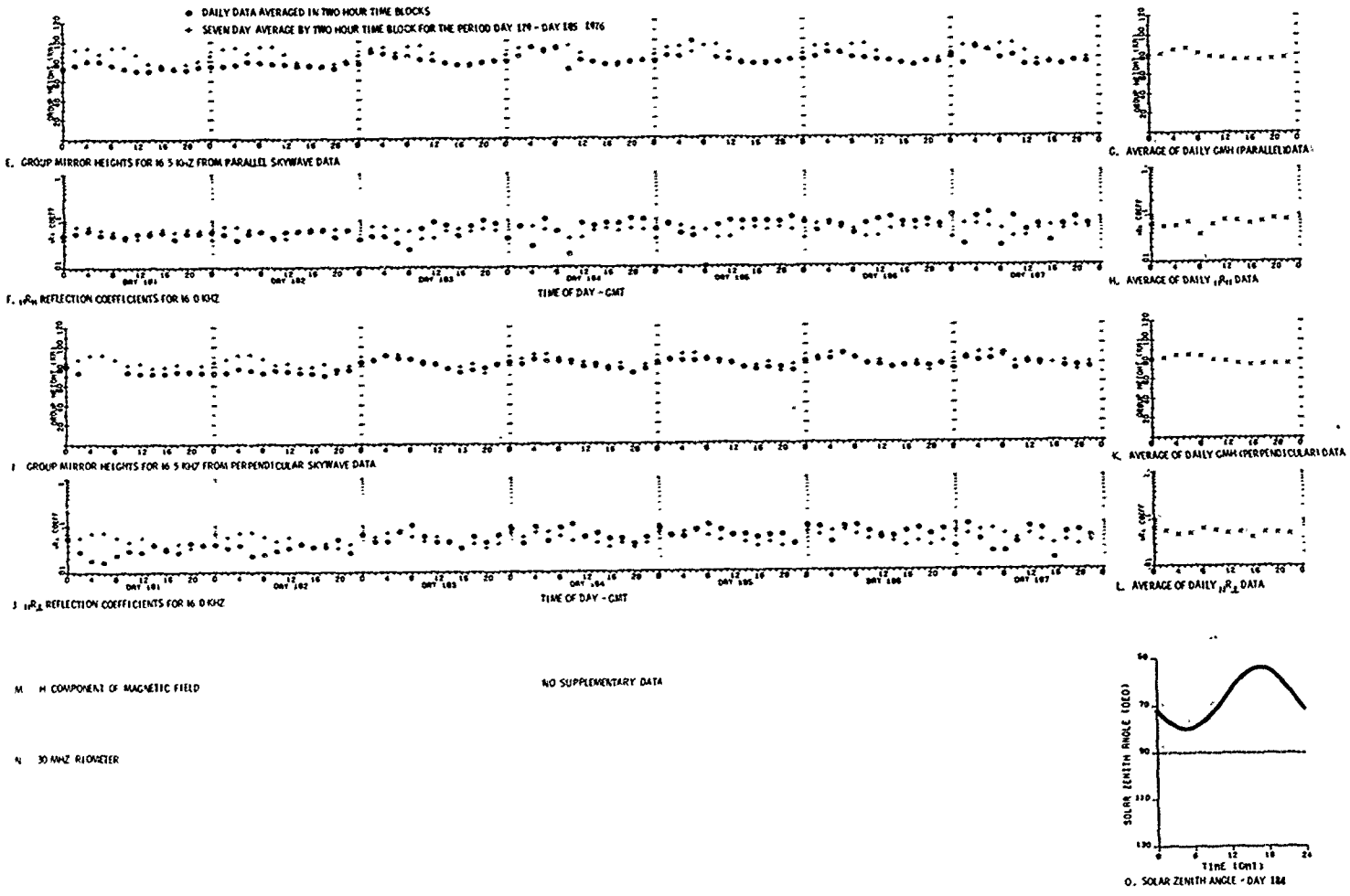

Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 181 (29 Jun) — DAY 187 (5 Jul) 1980 (Cont)

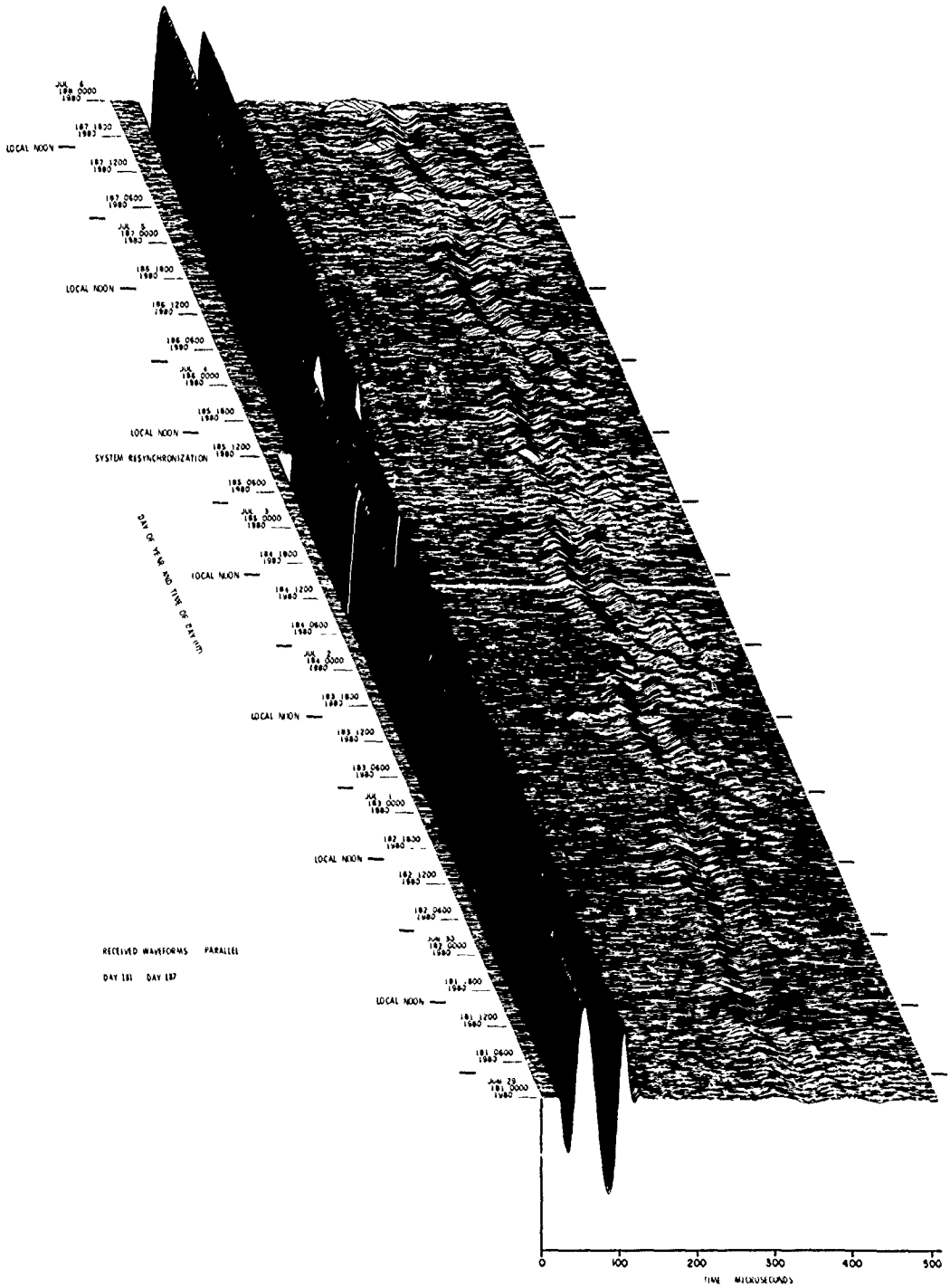

Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 181 (29 Jun) – DAY 187 (5 Jul) 1980 (Cont)
Part R. || Waveform Display

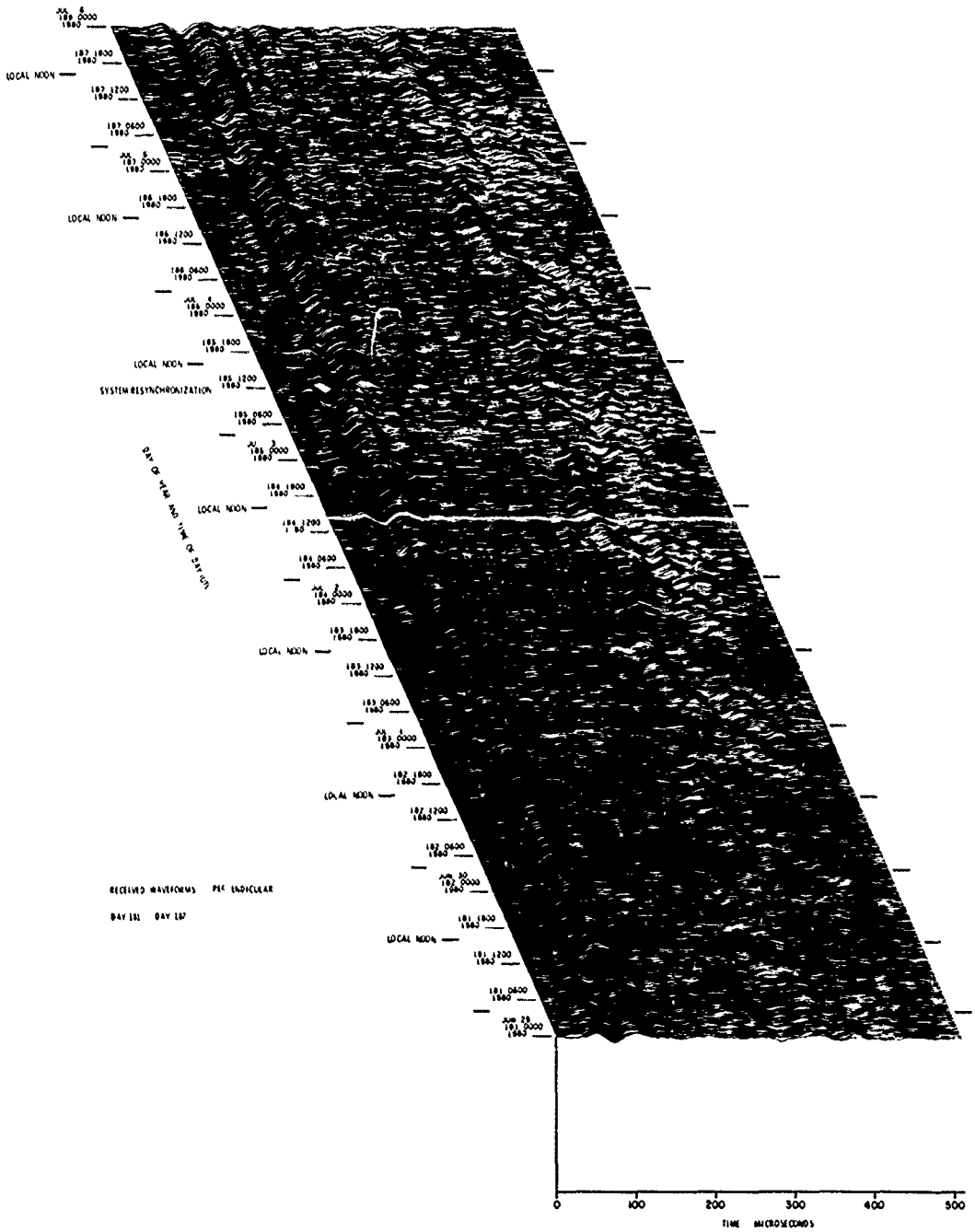

Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 181 (29 Jun) – DAY 187 (5 Jul) 1980 (Cont)
Part S. ⊥ Waveform Display

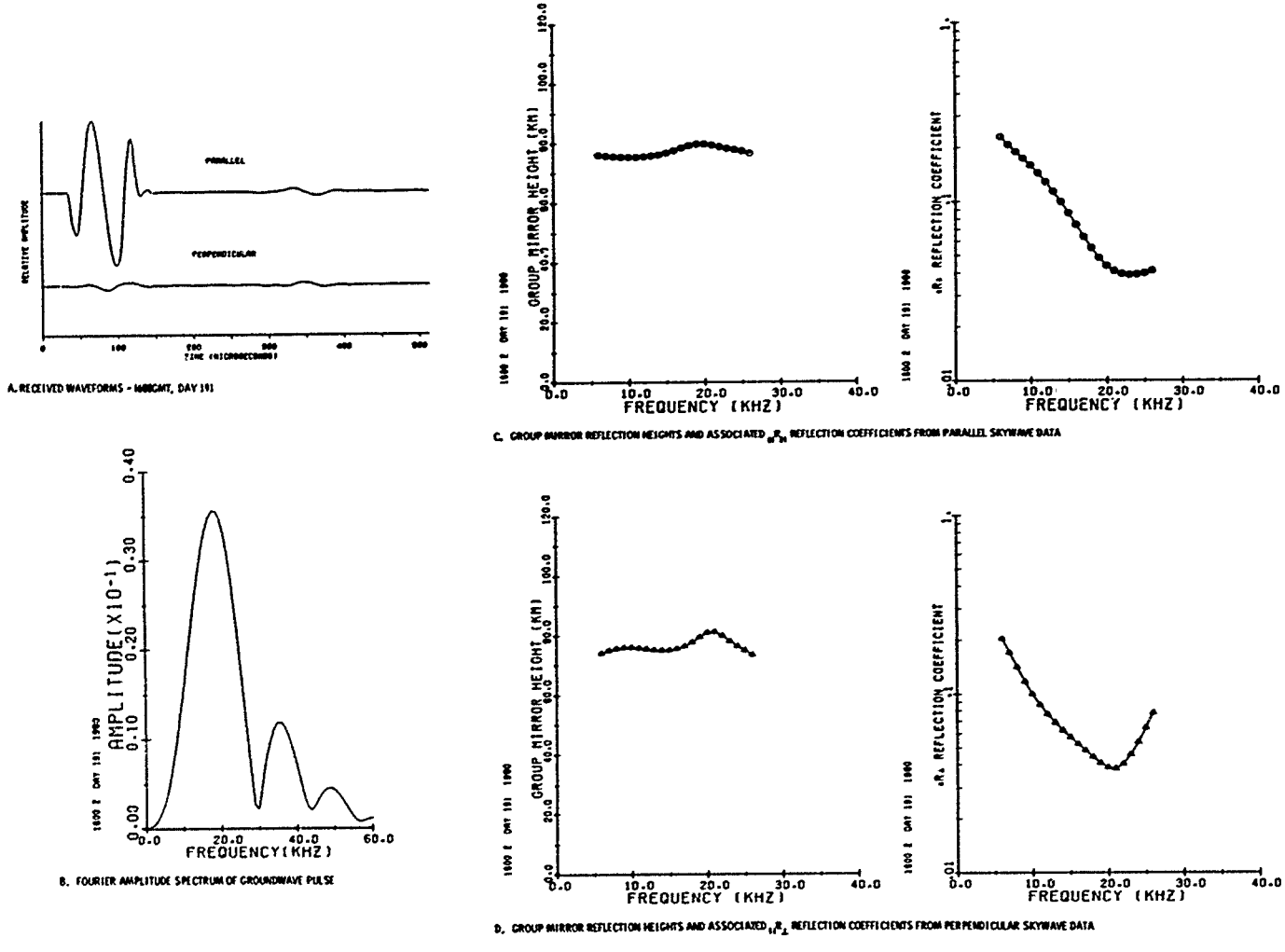

Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 188 (6 Jul) — DAY 194 (12 Jul) 1980

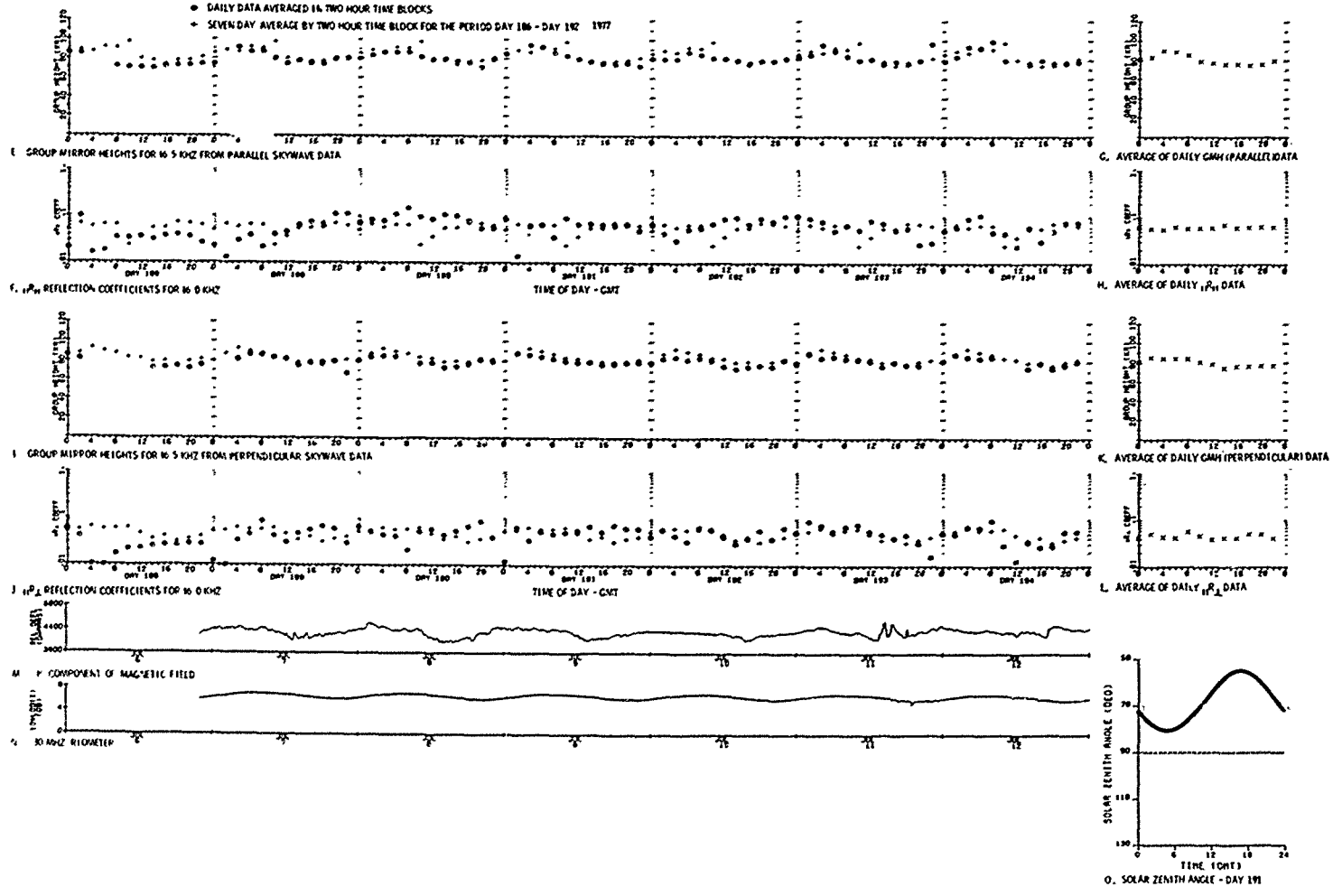

Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 188 (6 Jul) – DAY 194 (12 Jul) 1980 (Cont)

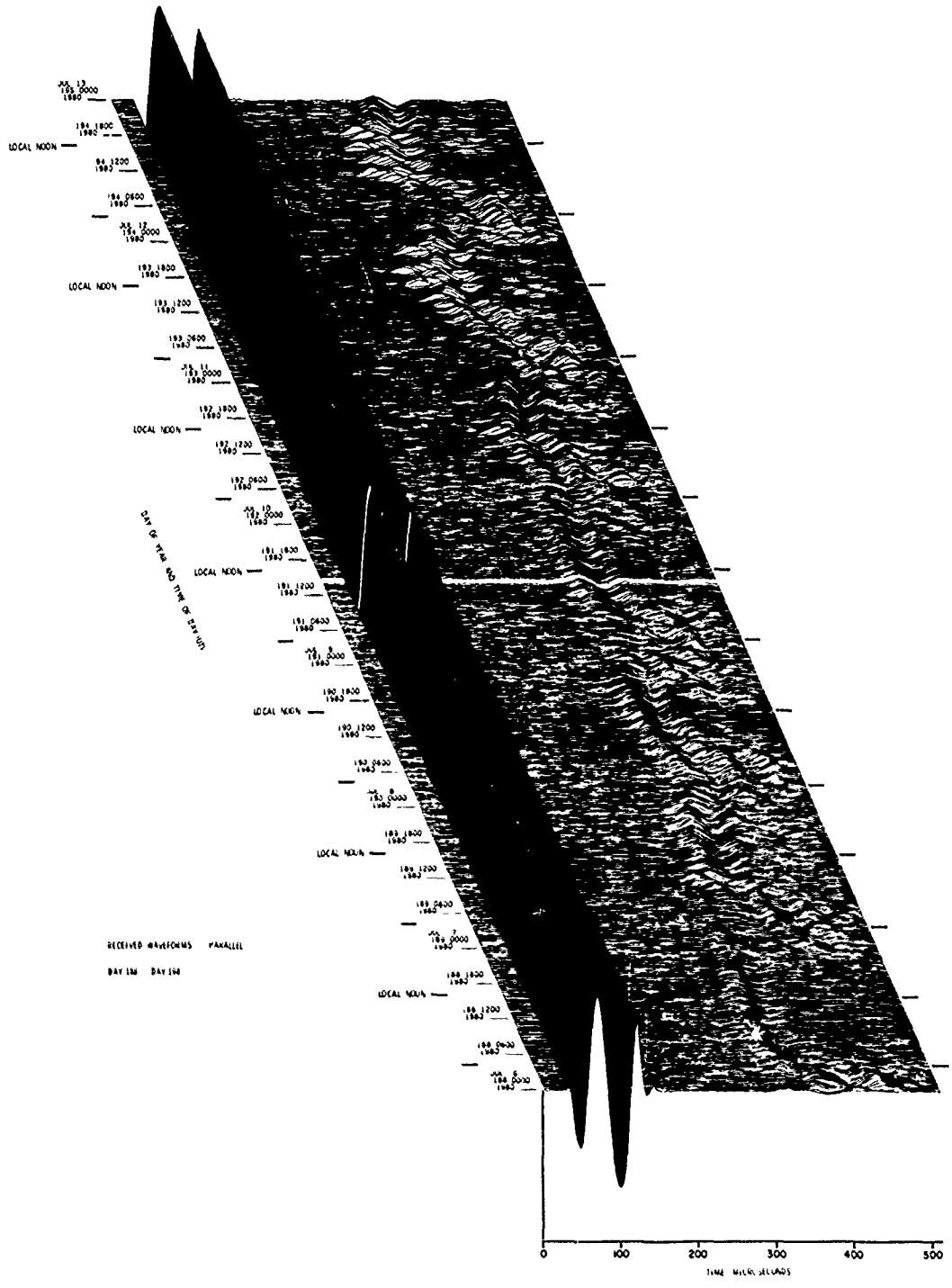

Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 188 (6 Jul) – DAY 194 (12 Jul) 1980 (Cont)
Part R. || Waveform Display

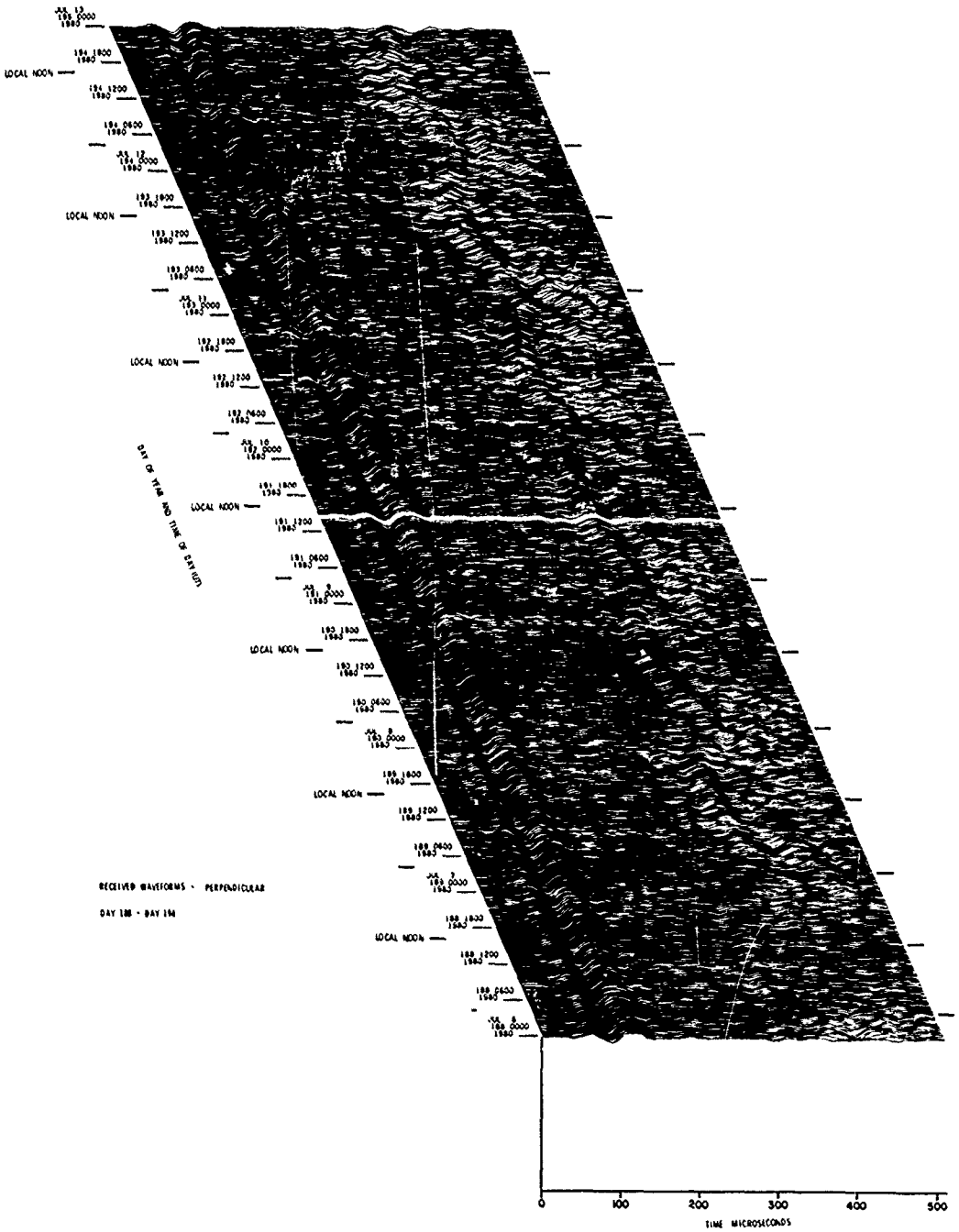

Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 188 (6 Jul) — DAY 194 (12 Jul) 1980 (Cont)
Part S. ⊥ Waveform Display

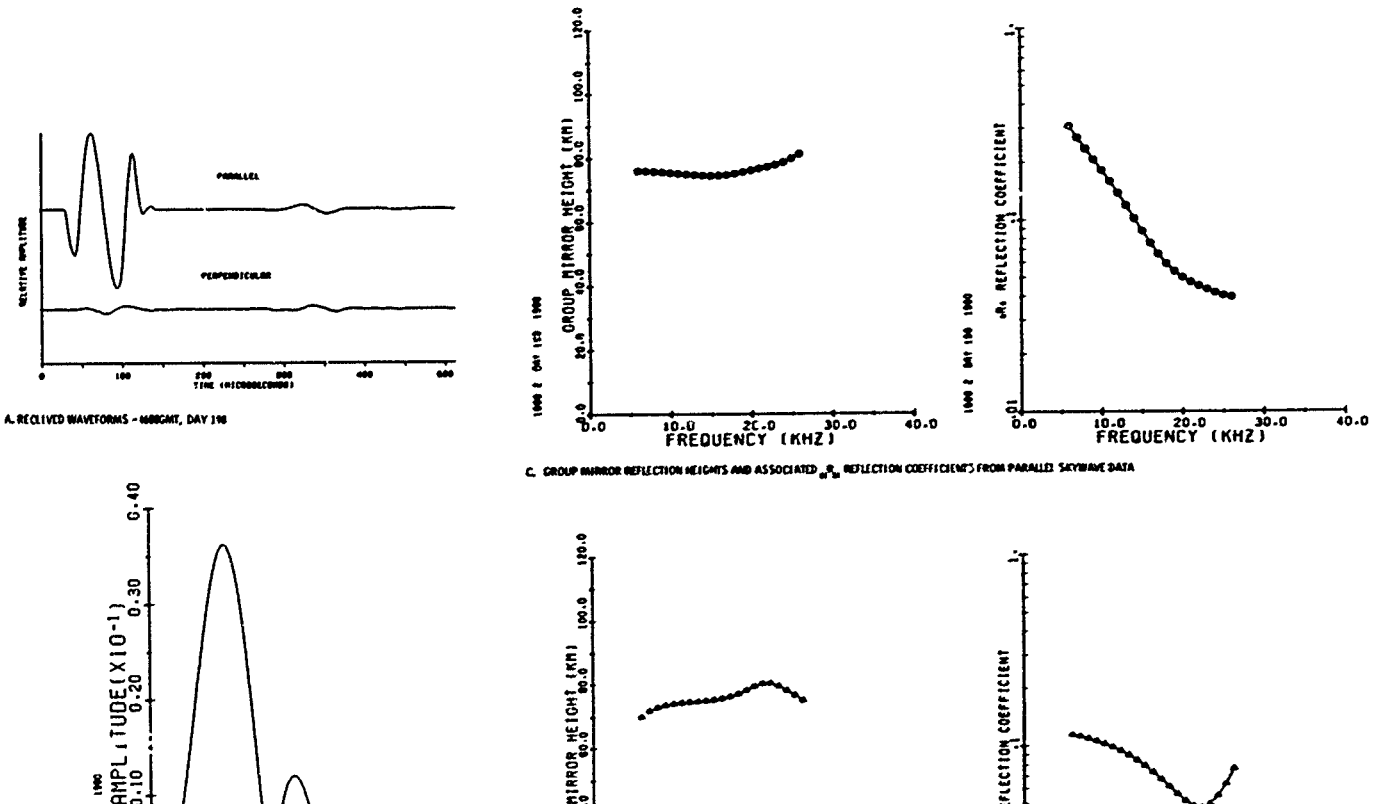

Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 195 (13 Jul) – DAY 201 (19 Jul) 1980

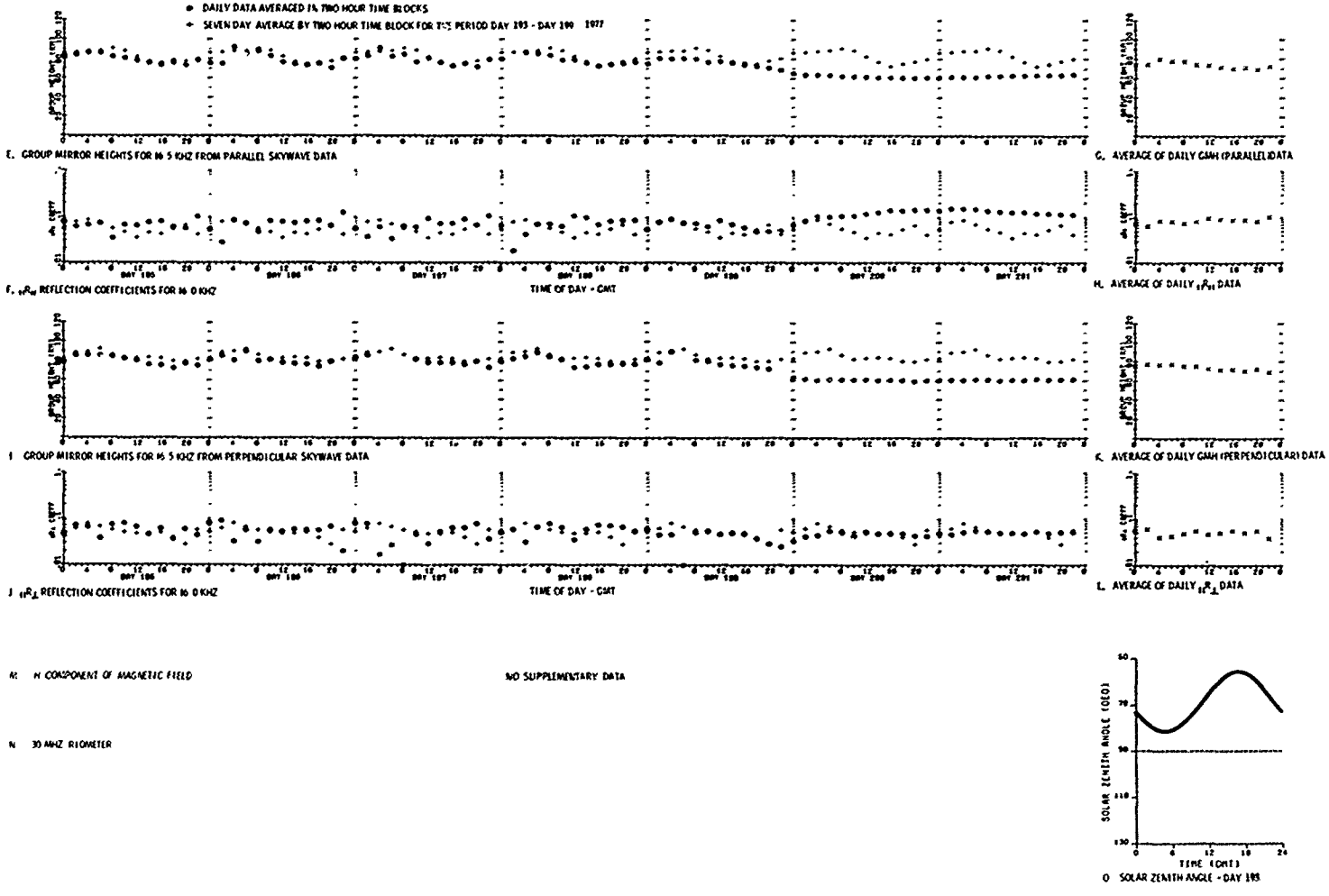

Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 195 (13 Jul) — DAY 201 (19 Jul) 1980 (Cont)

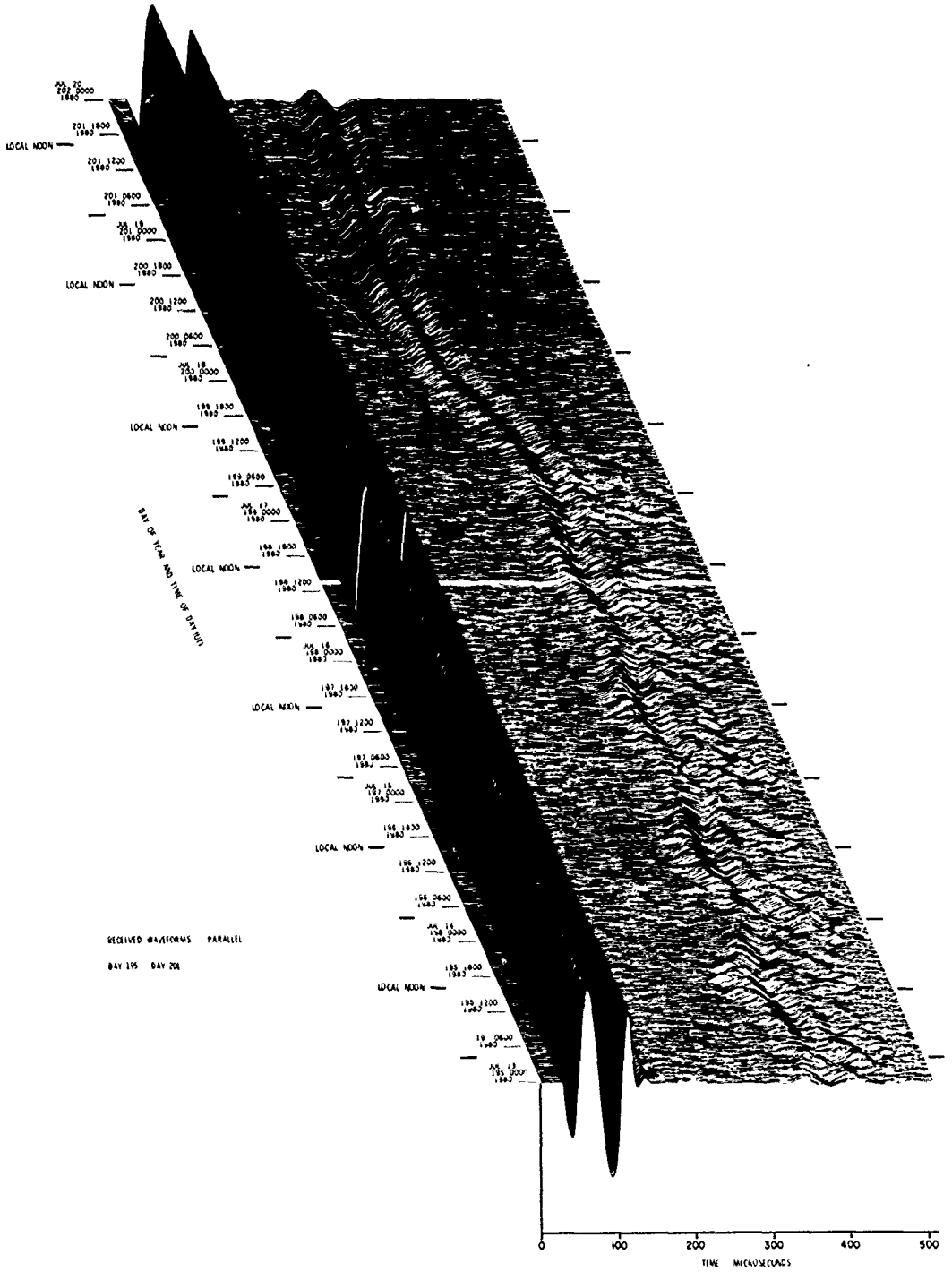

Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 195 (13 Jul) – DAY 201 (19 Jul) 1980 (Cont)
Part R. || Waveform Display

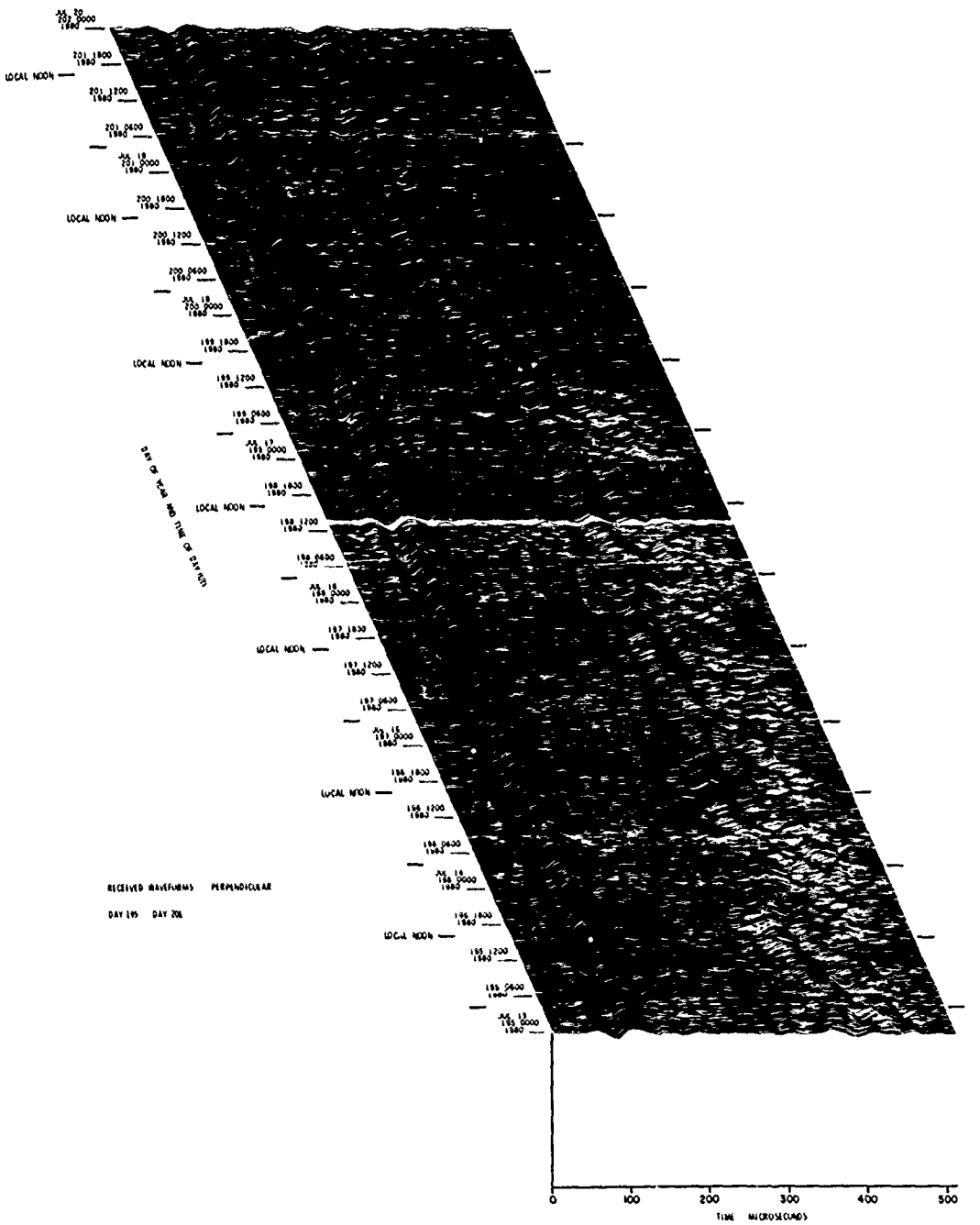

Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 195 (13 Jul) – DAY 201 (19 Jul) 1980 (Cont)
Part S. ⊥Waveform Display

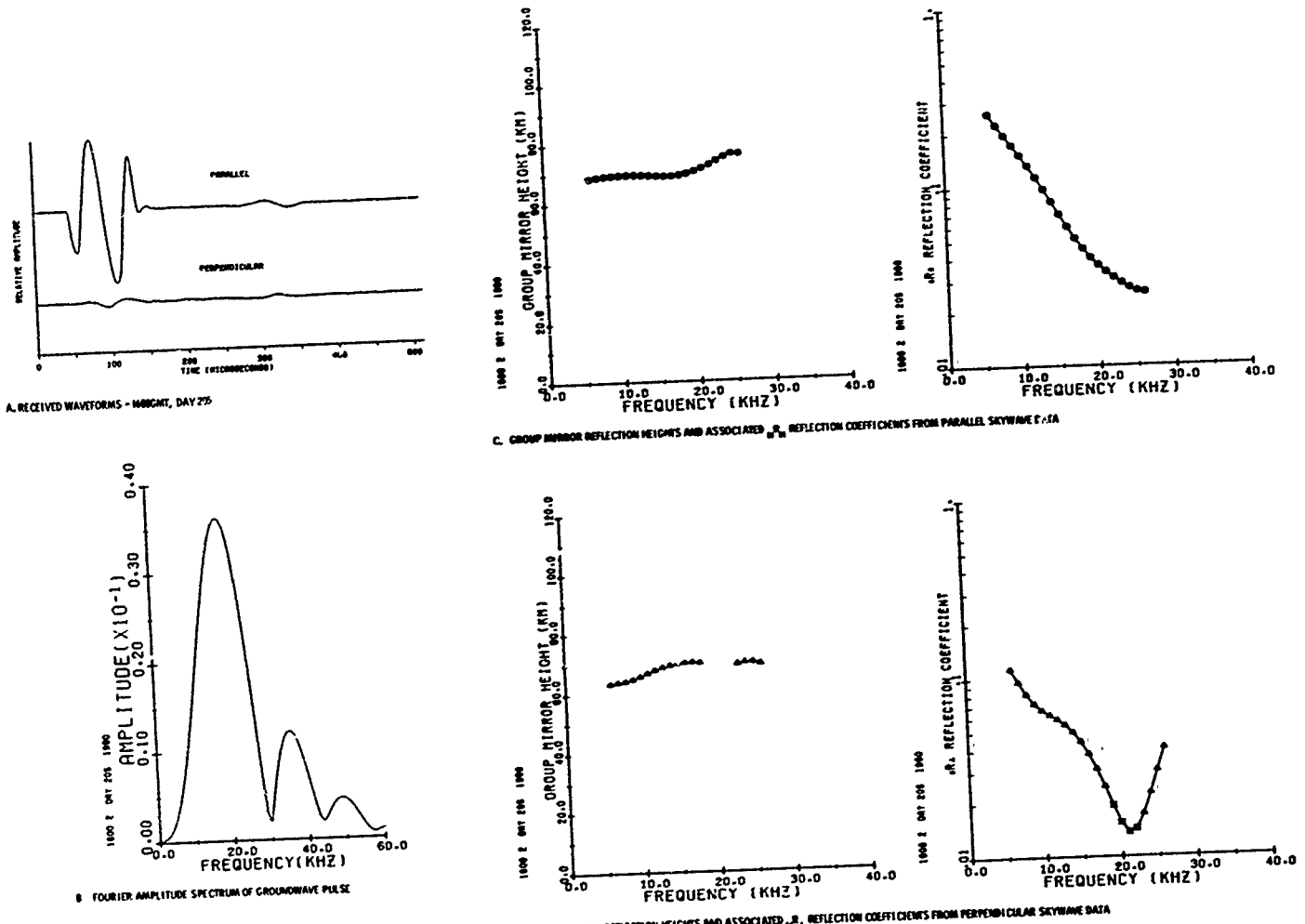

Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 202 (20 Jul) — DAY 208 (26 Jul) 1980

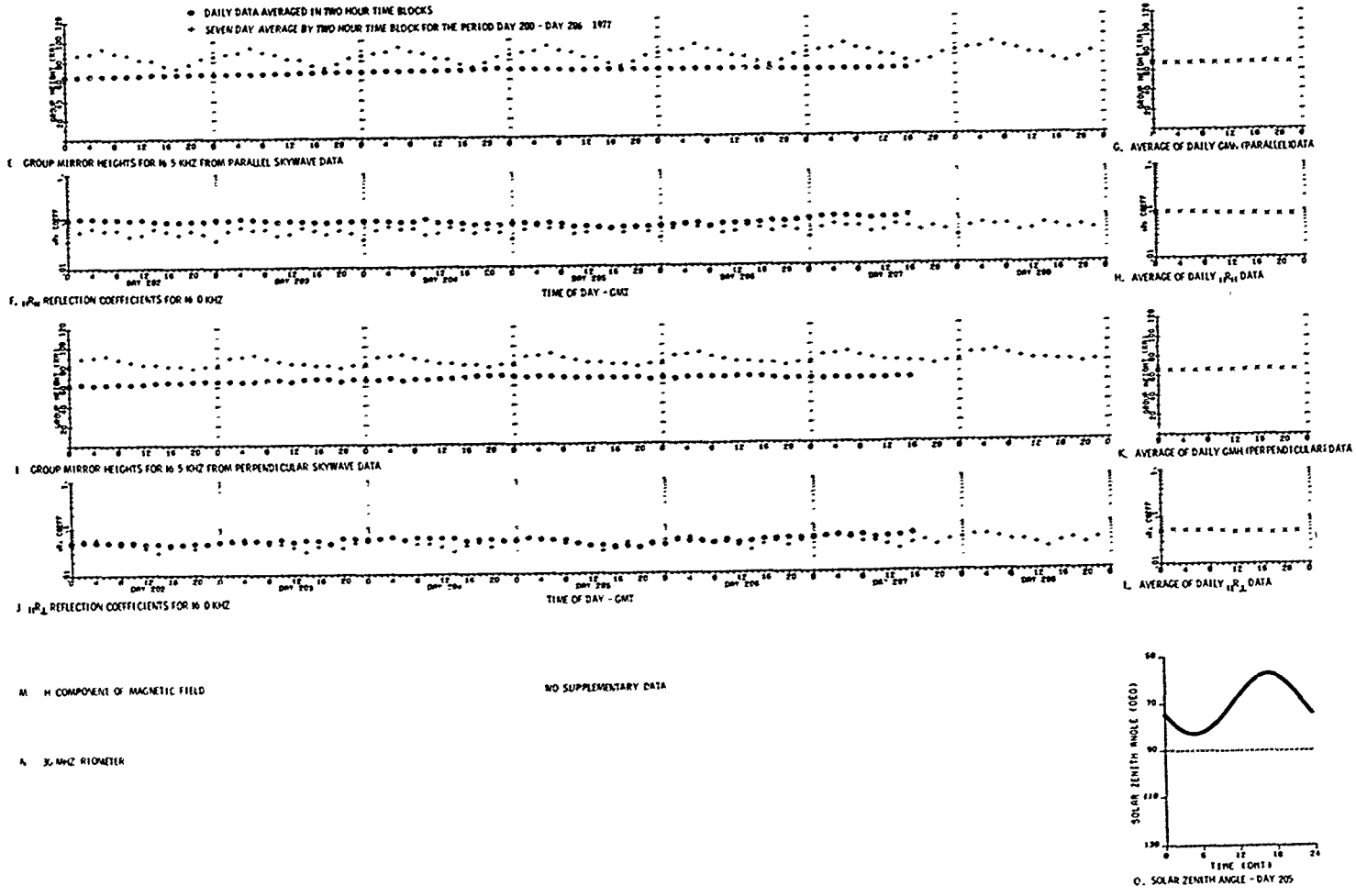

Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 202 (20 Jul) — DAY 208 (26 Jul) 1980 (Cont)

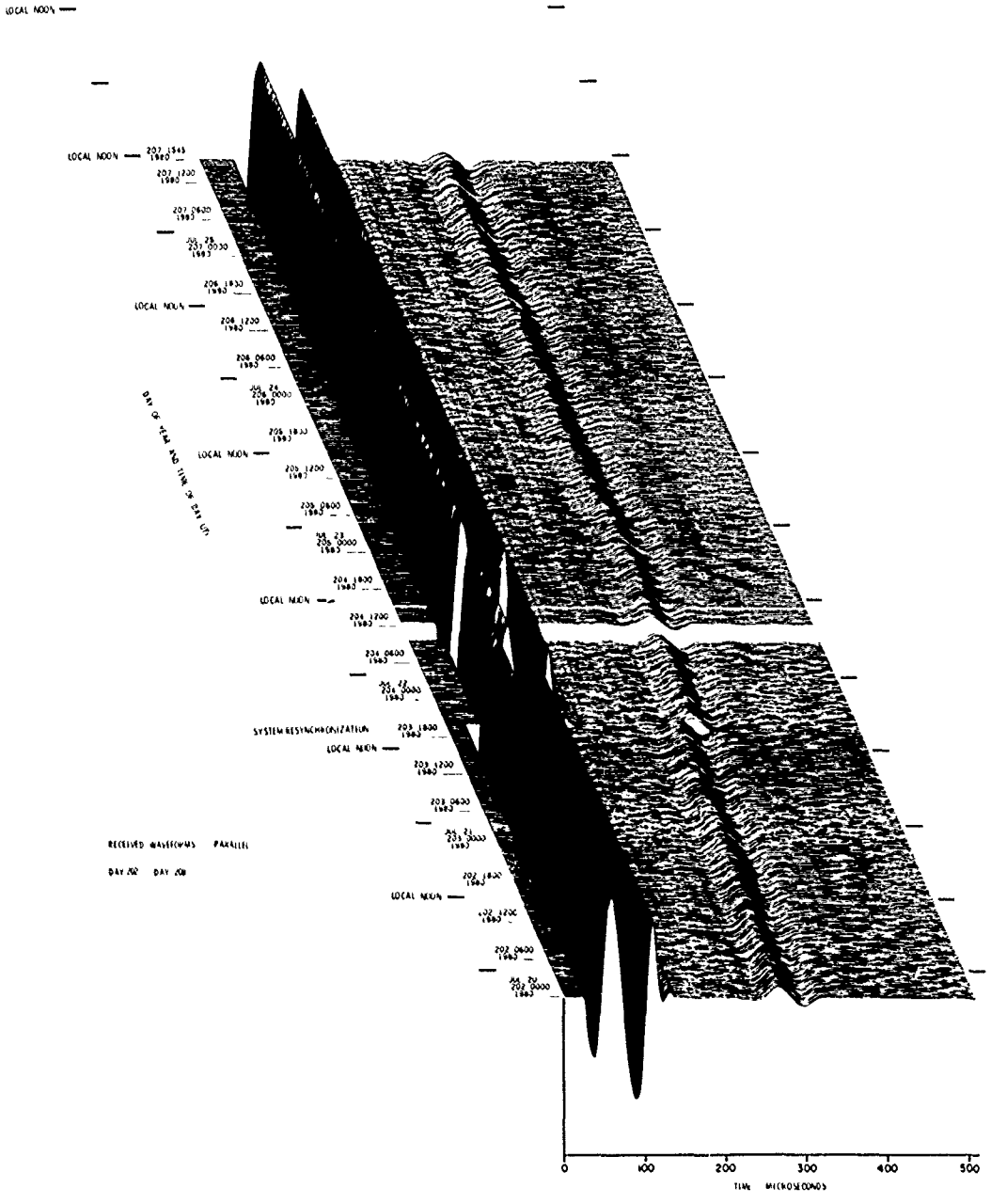

Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 202 (20 Jul) – DAY 208 (26 Jul) 1980 (Cont)
Part R. || Waveform Display

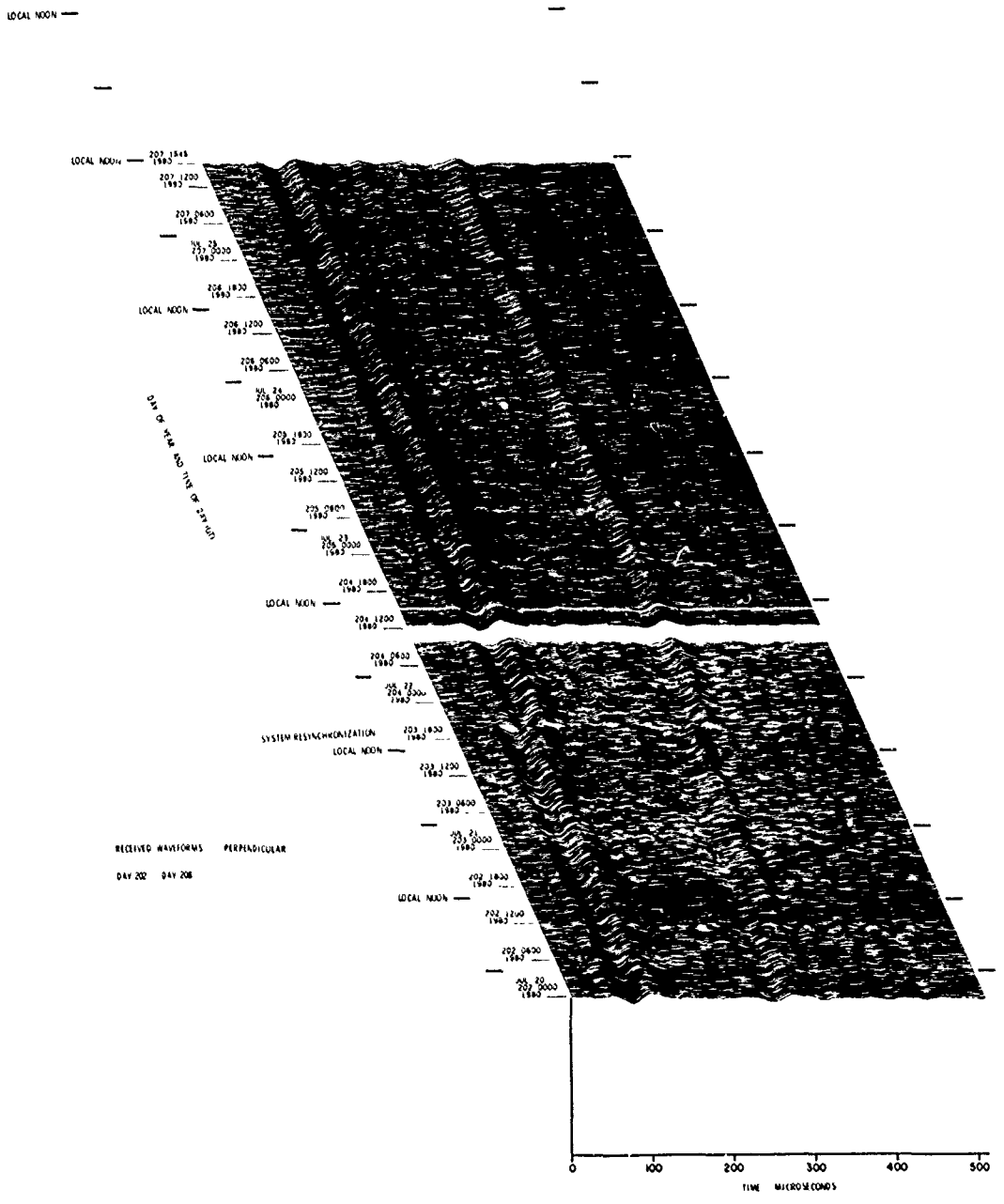

Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 202 (20 Jul) – DAY 208 (26 Jul) 1980 (Cont)
Part S. $\perp$ Waveform Display

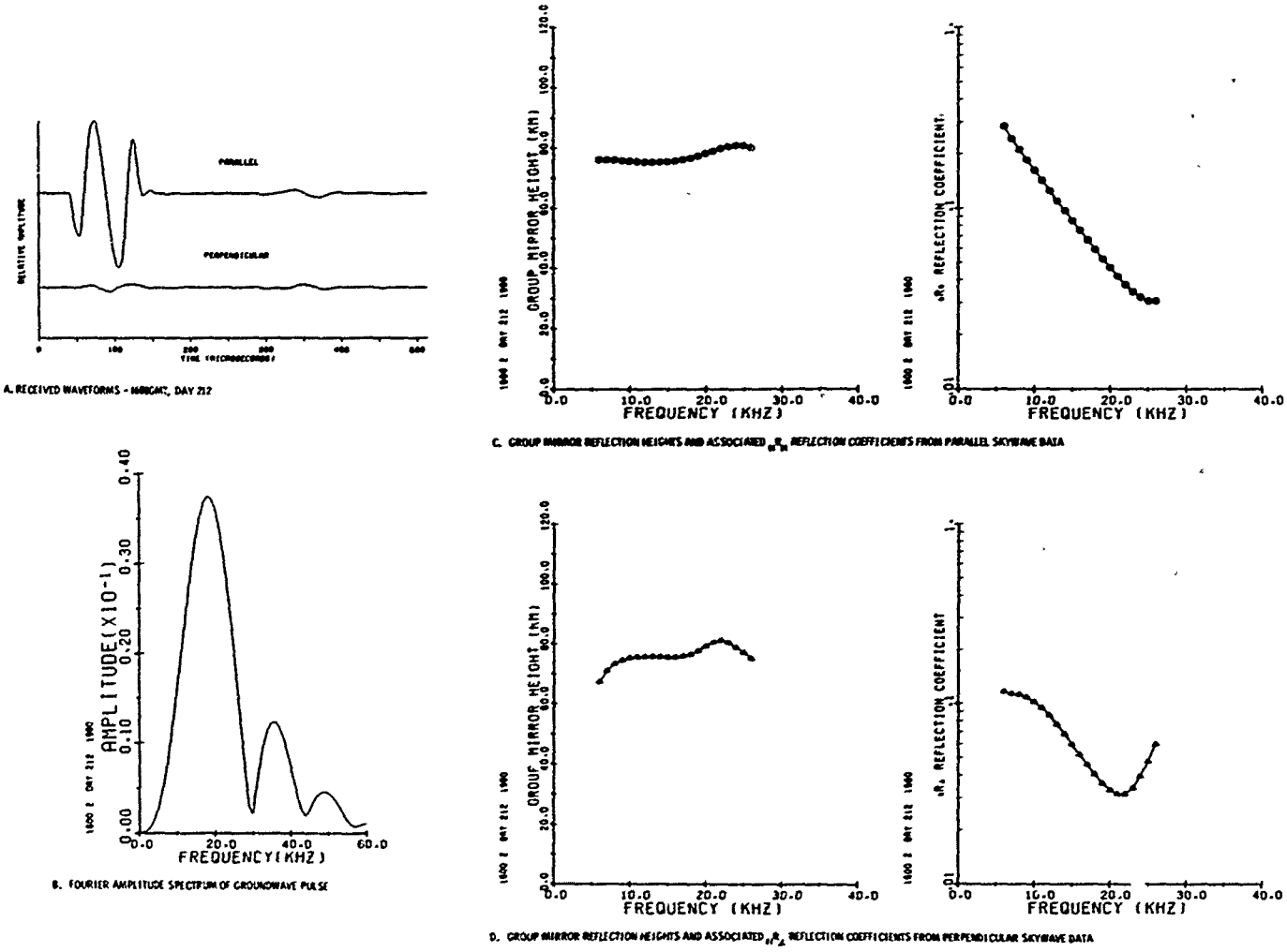

Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 209 (27 Jul) — DAY 215 (2 Aug) 1980

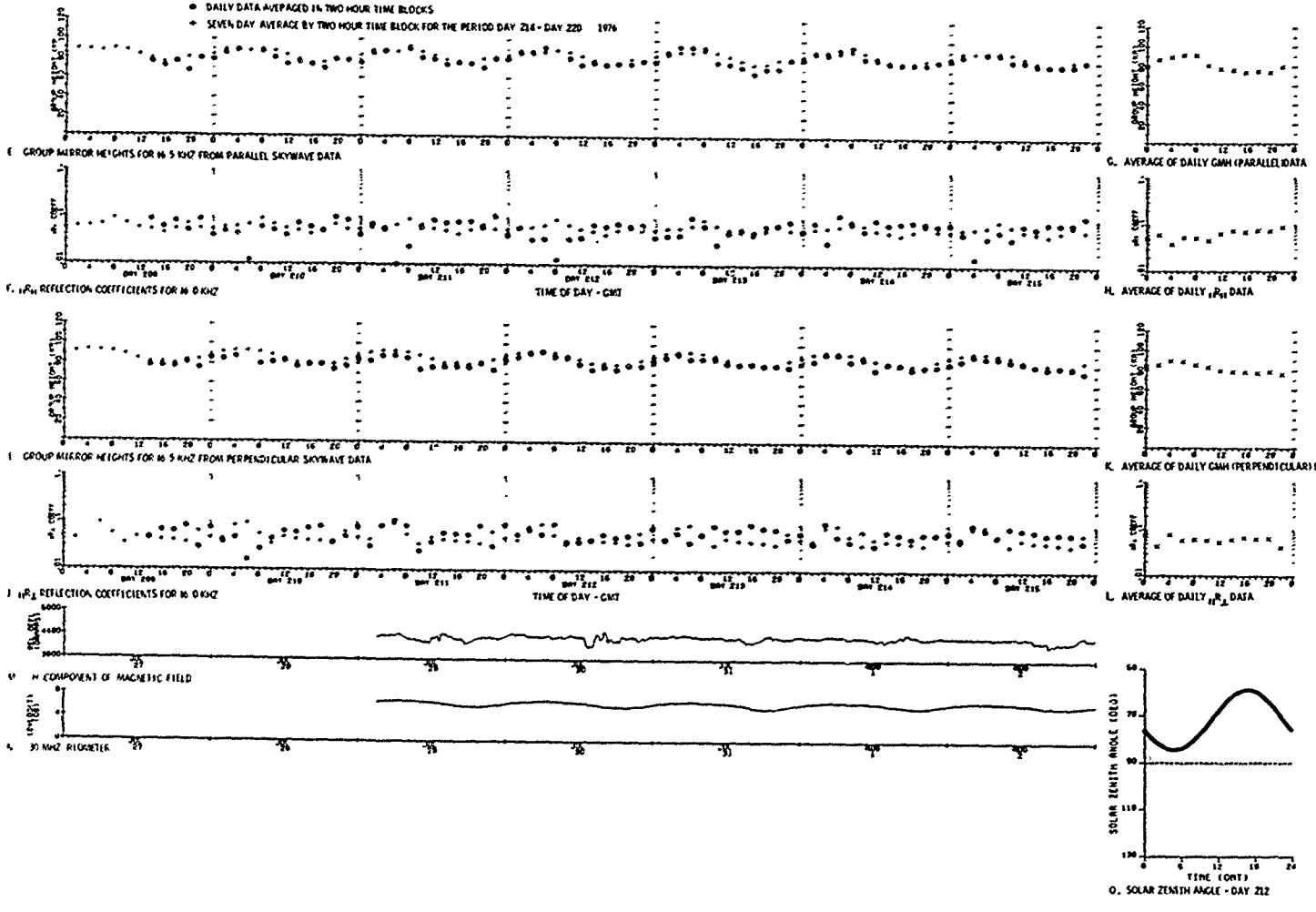

Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 209 (27 Jul) — DAY 215 (2 Aug) 1980 (Cont)

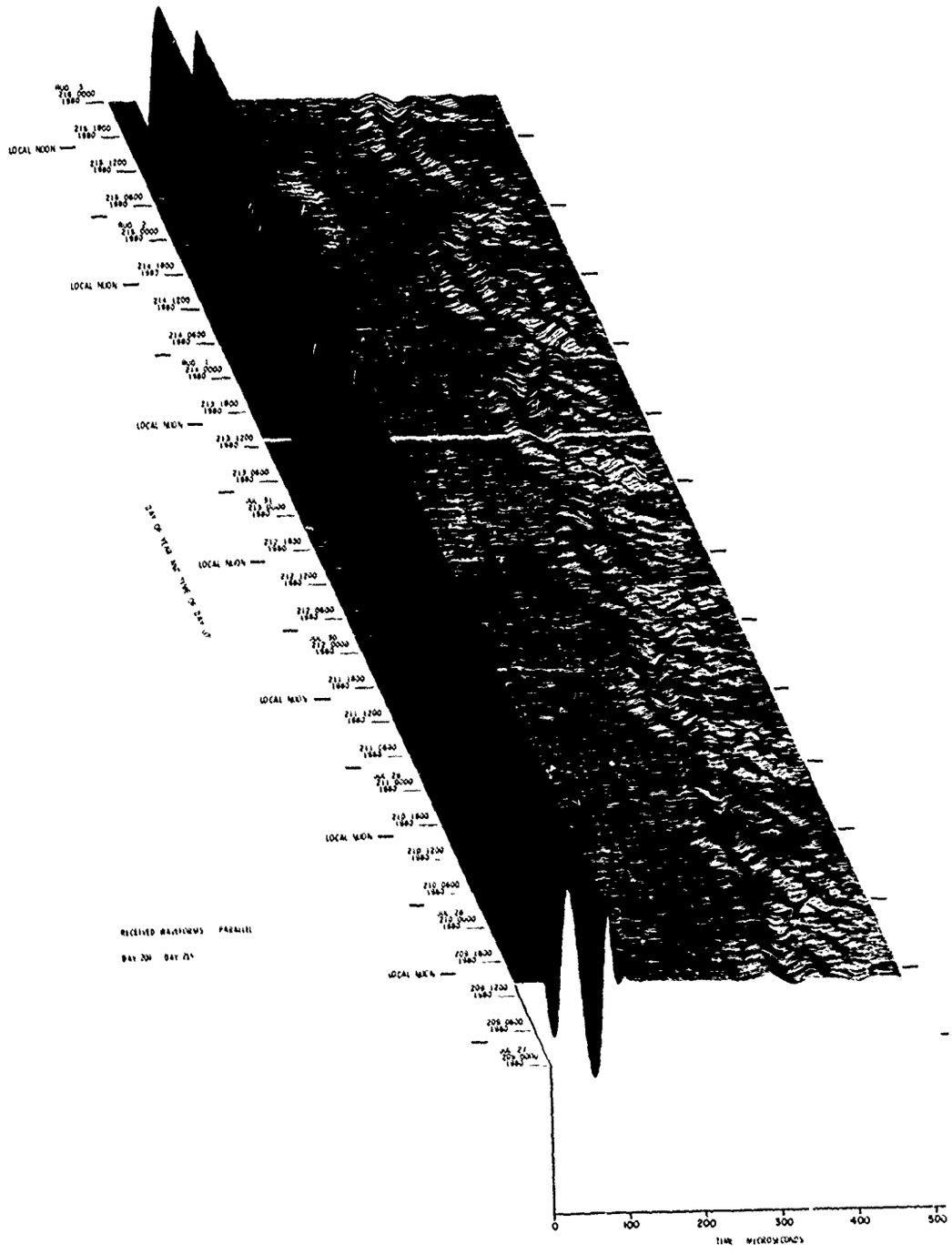

Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 209 (27 Jul) – DAY 215 (2 Aug) 1980 (Cont)
Part R. || Waveform Display

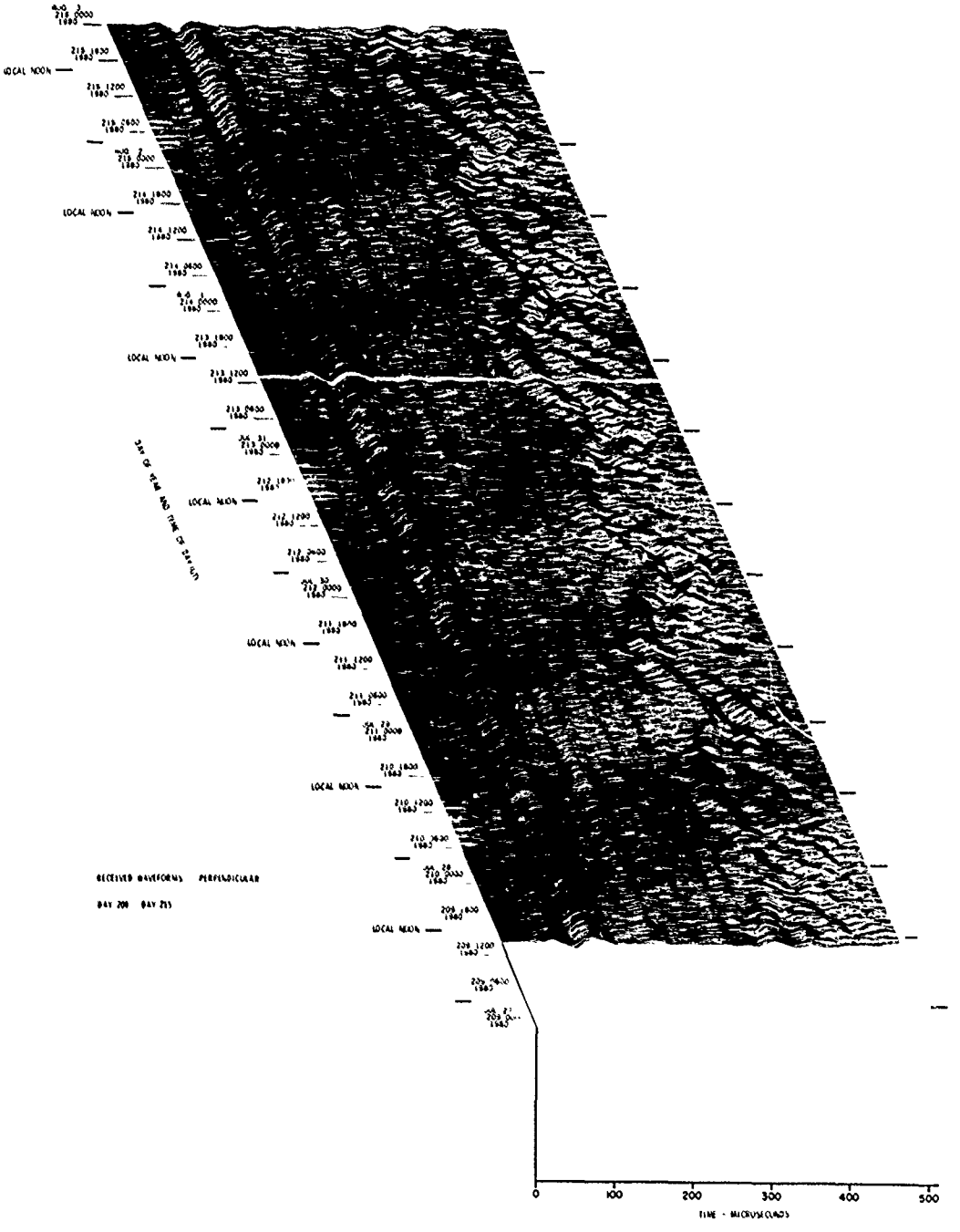

Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 209 (27 Jul) – DAY 215 (2 Aug) 1980 (Cont)
Part S. ⊥ Waveform Display

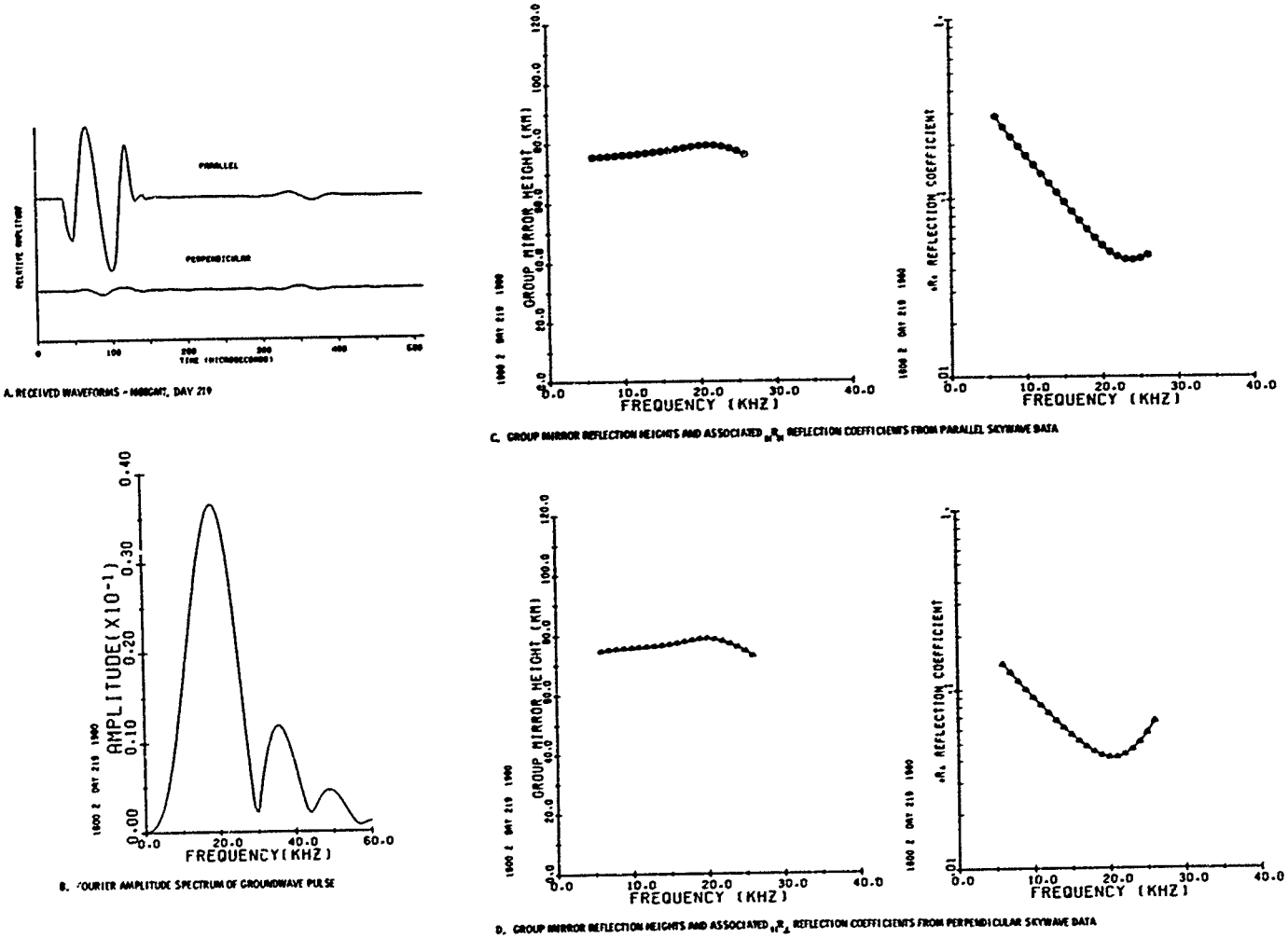

Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 216 (3 Aug) — DAY 222 (9 Aug) 1980

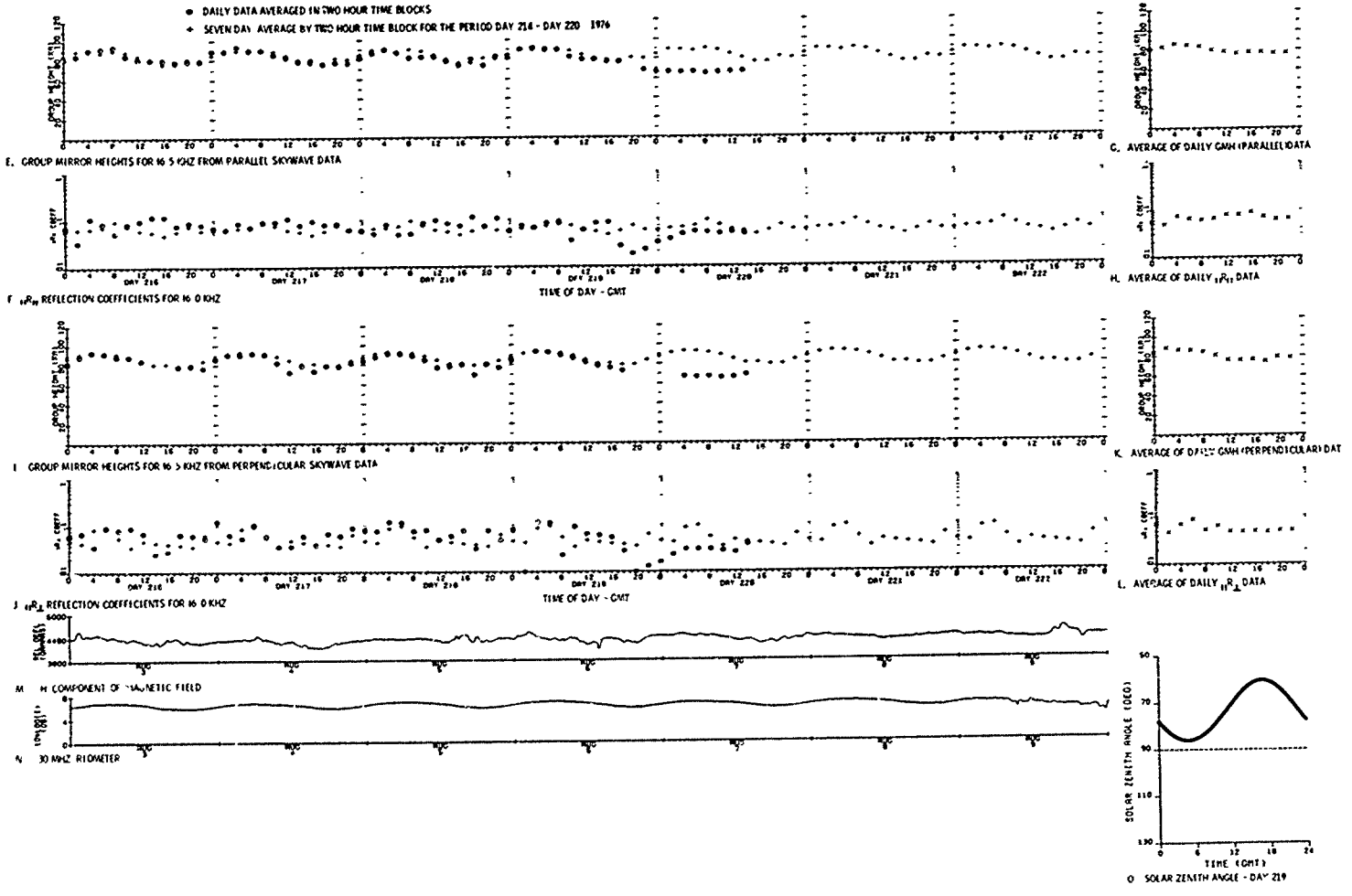

Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 216 (3 Aug) — DAY 222 (9 Aug) 1980 (Cont)

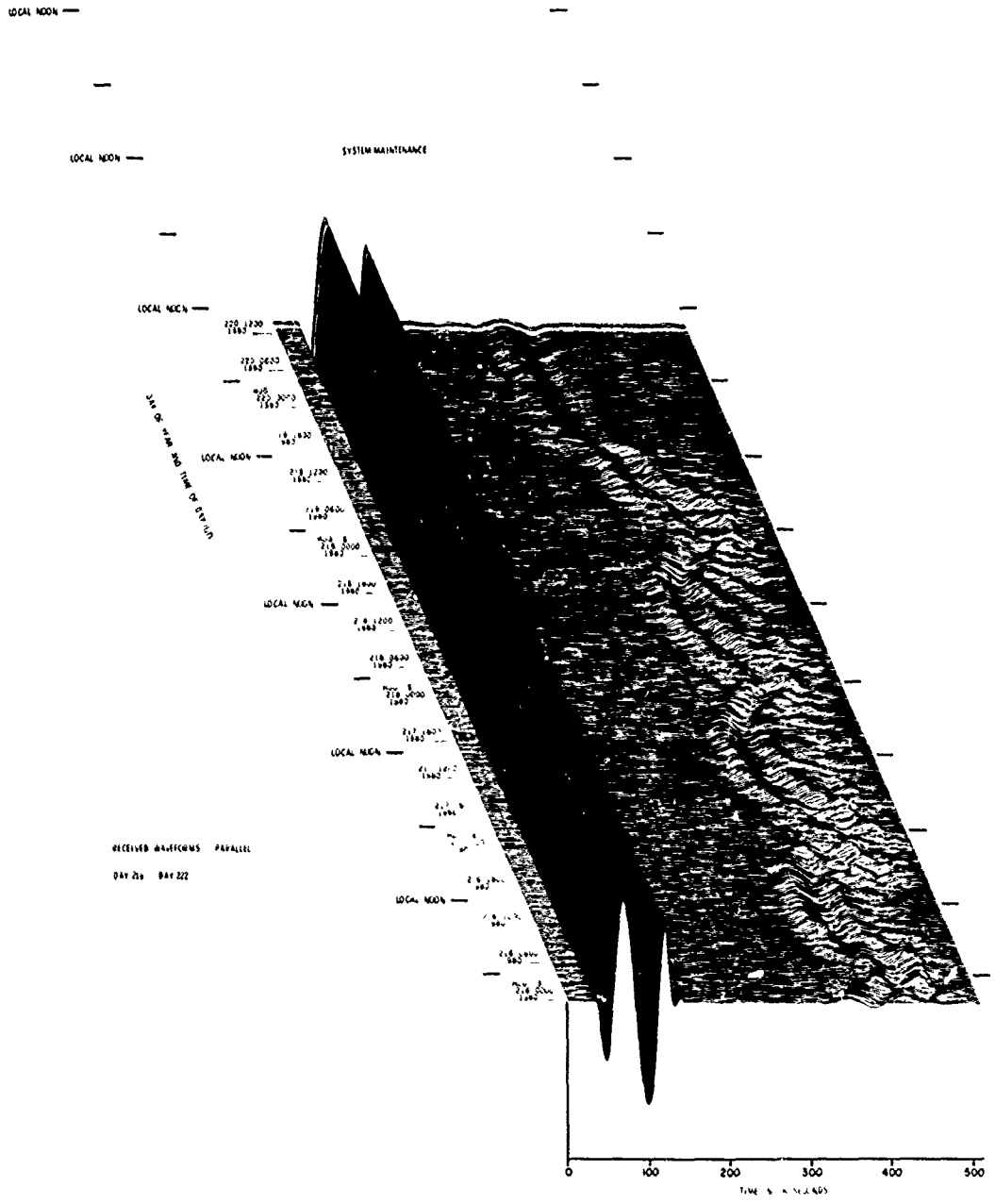

Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 216 (3 Aug) – DAY 222 (9 Aug) 1980 (Cont)
Part R. || Waveform Display

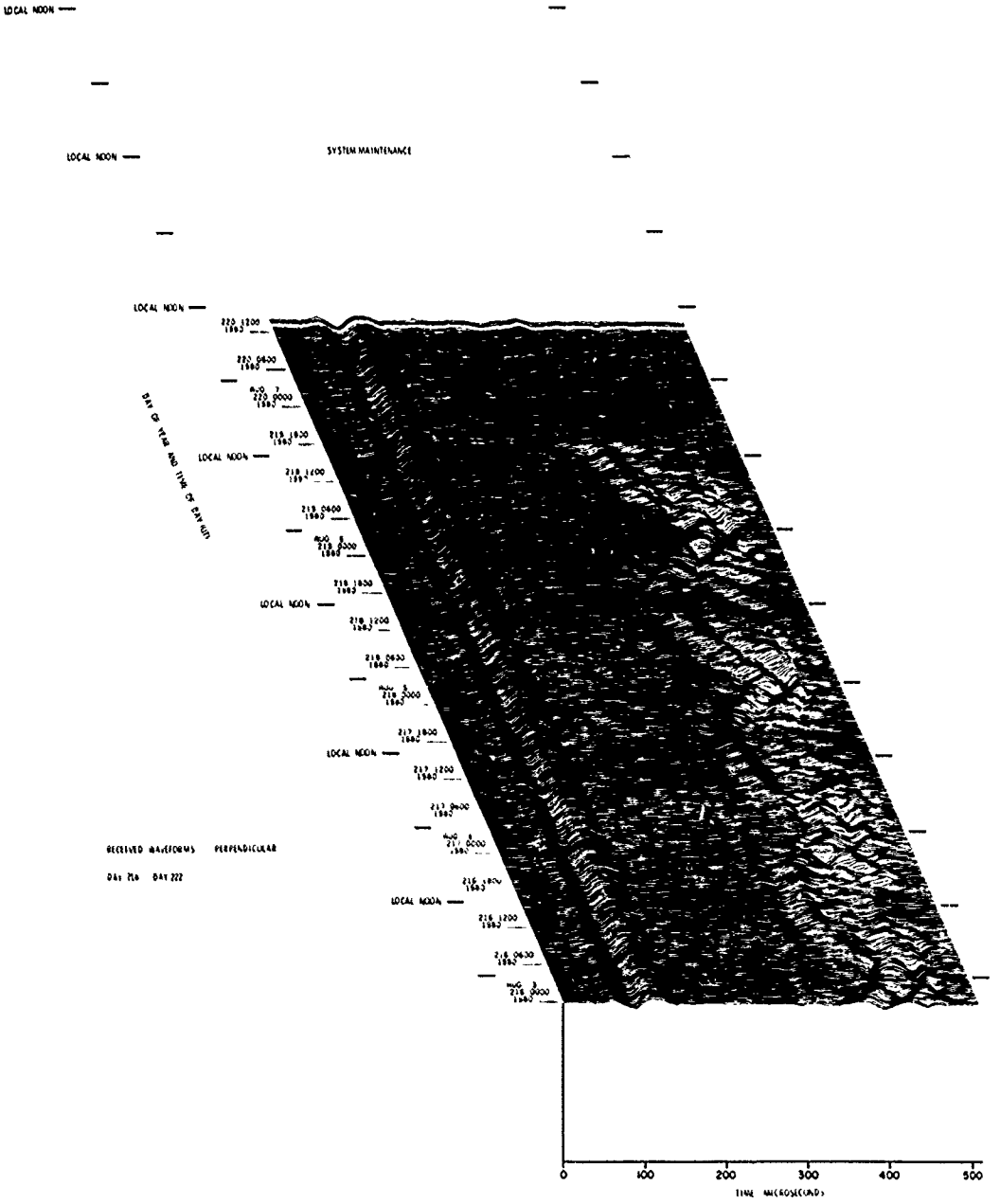

Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 216 (3 Aug) – DAY 222 (9 Aug) 1980 (Cont)
Part S. ⊥ Waveform Display

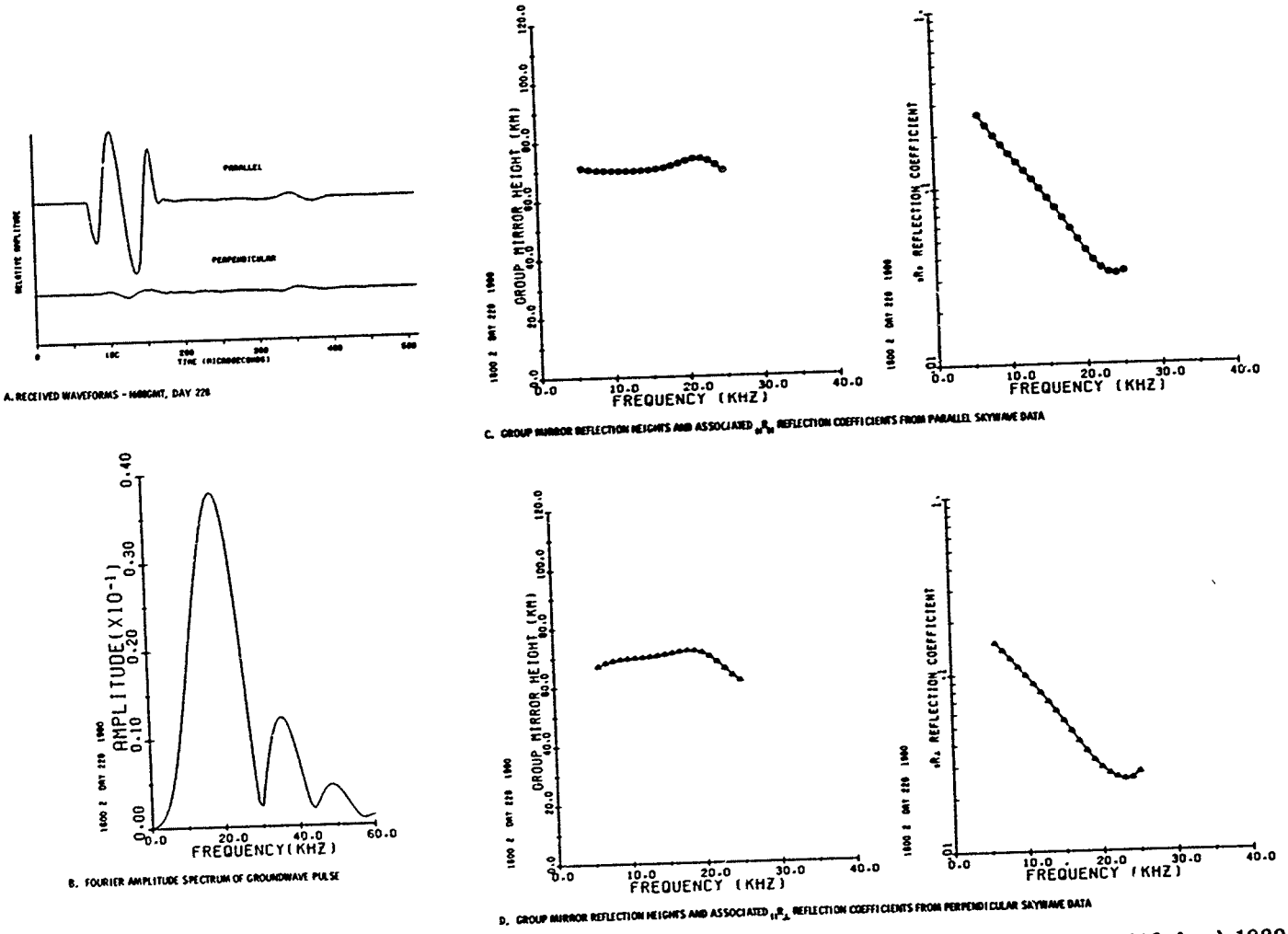

Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 223 (10 Aug) – DAY 229 (16 Aug) 1980

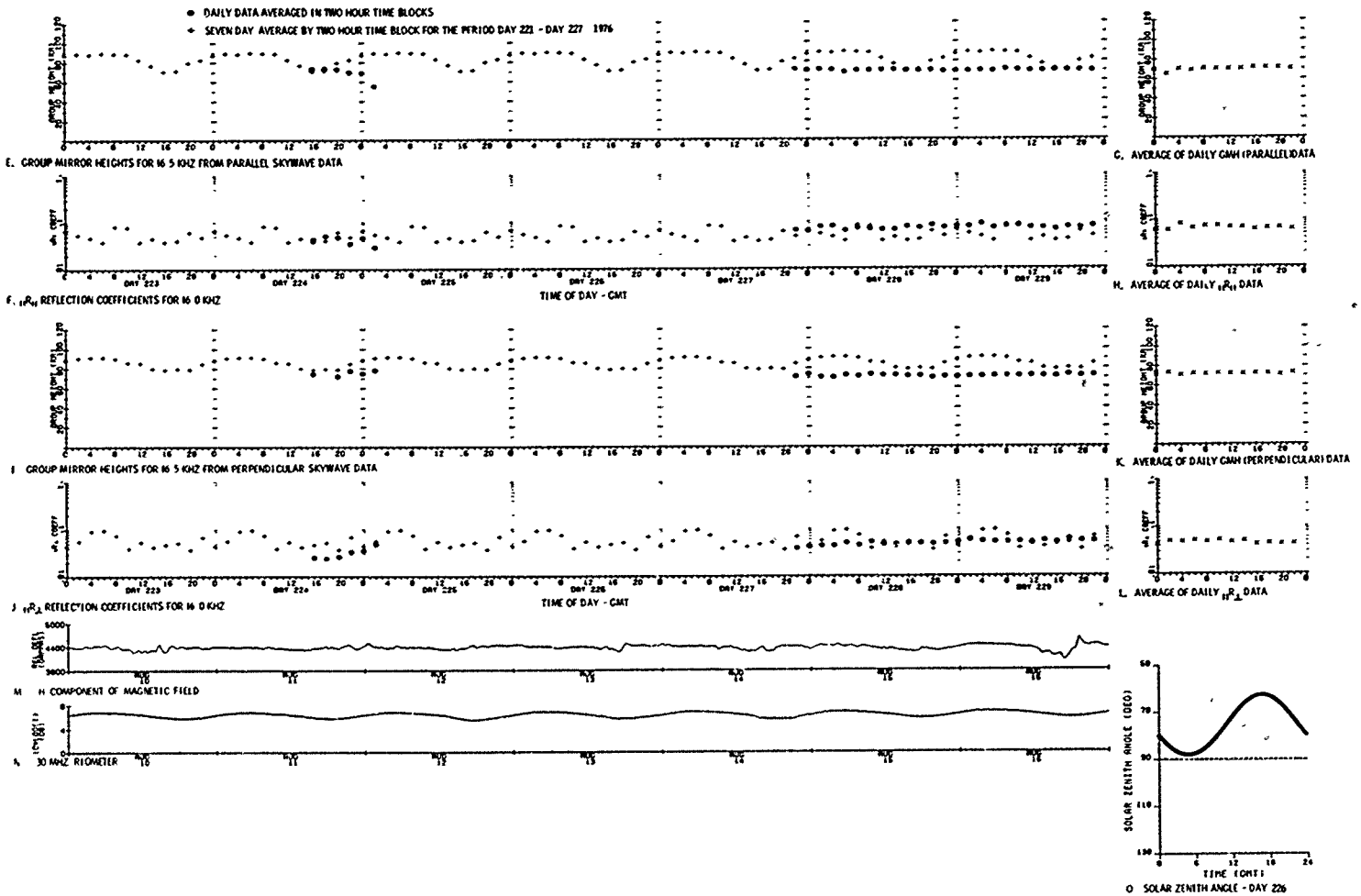

Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 223 (10 Aug) — DAY 229 (16 Aug) 1980 (Cont)

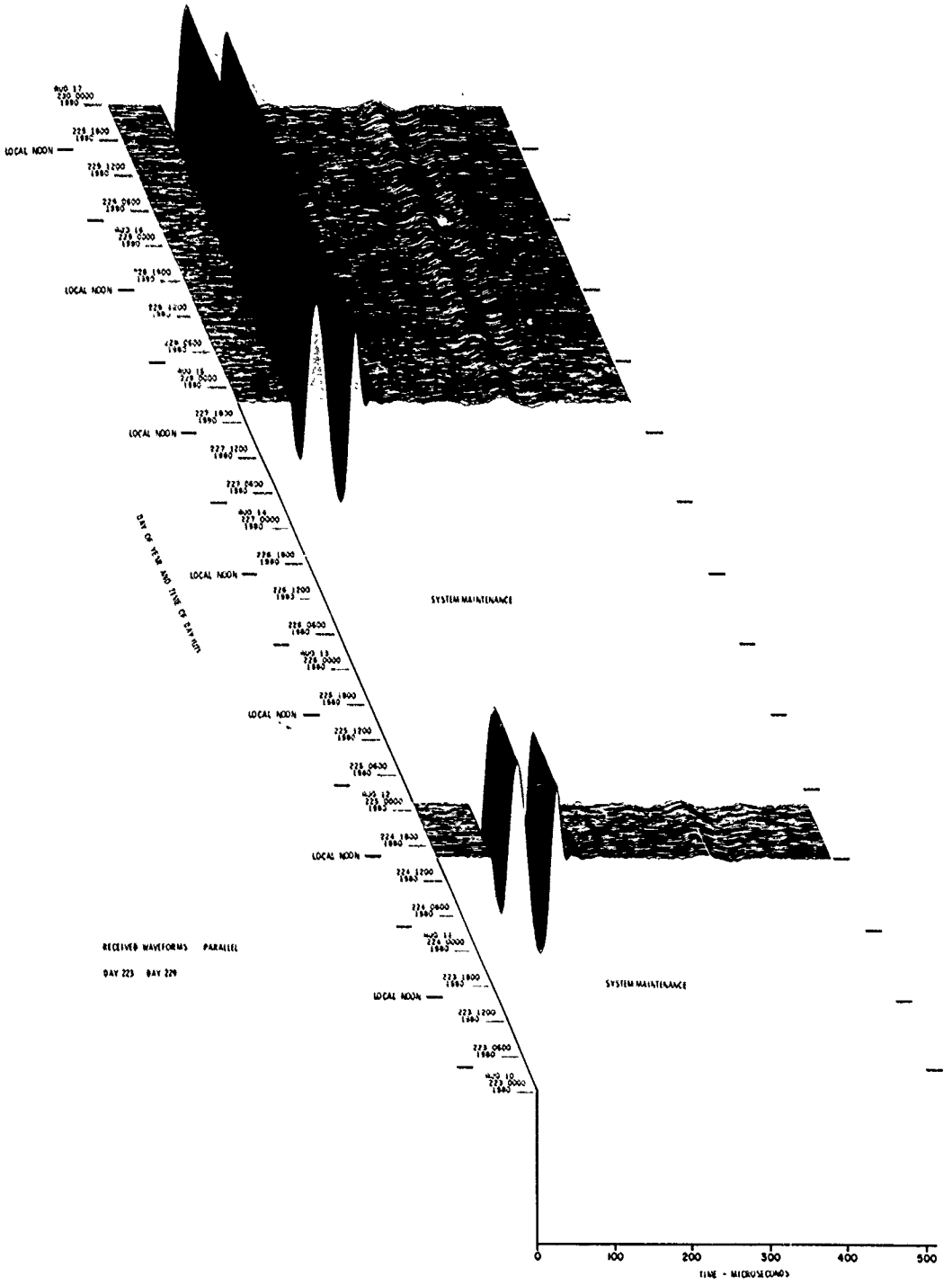

Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 223 (10 Aug) – DAY 229 (16 Aug) 1980 (Cont)
Part R. || Waveform Display

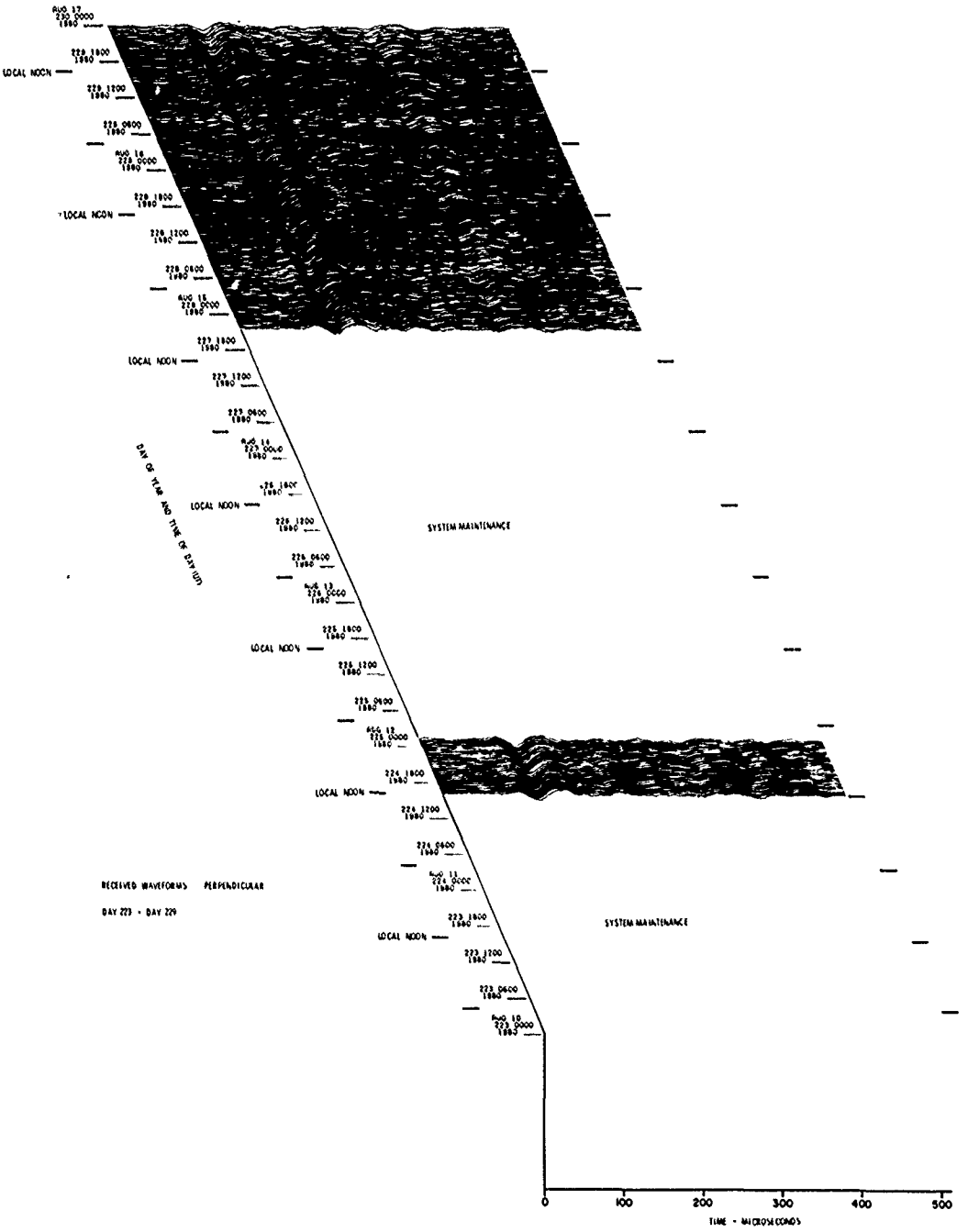

Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 223 (10 Aug) – DAY 229 (16 Aug) 1980 (Cont)
Part S. ⊥ Waveform Display

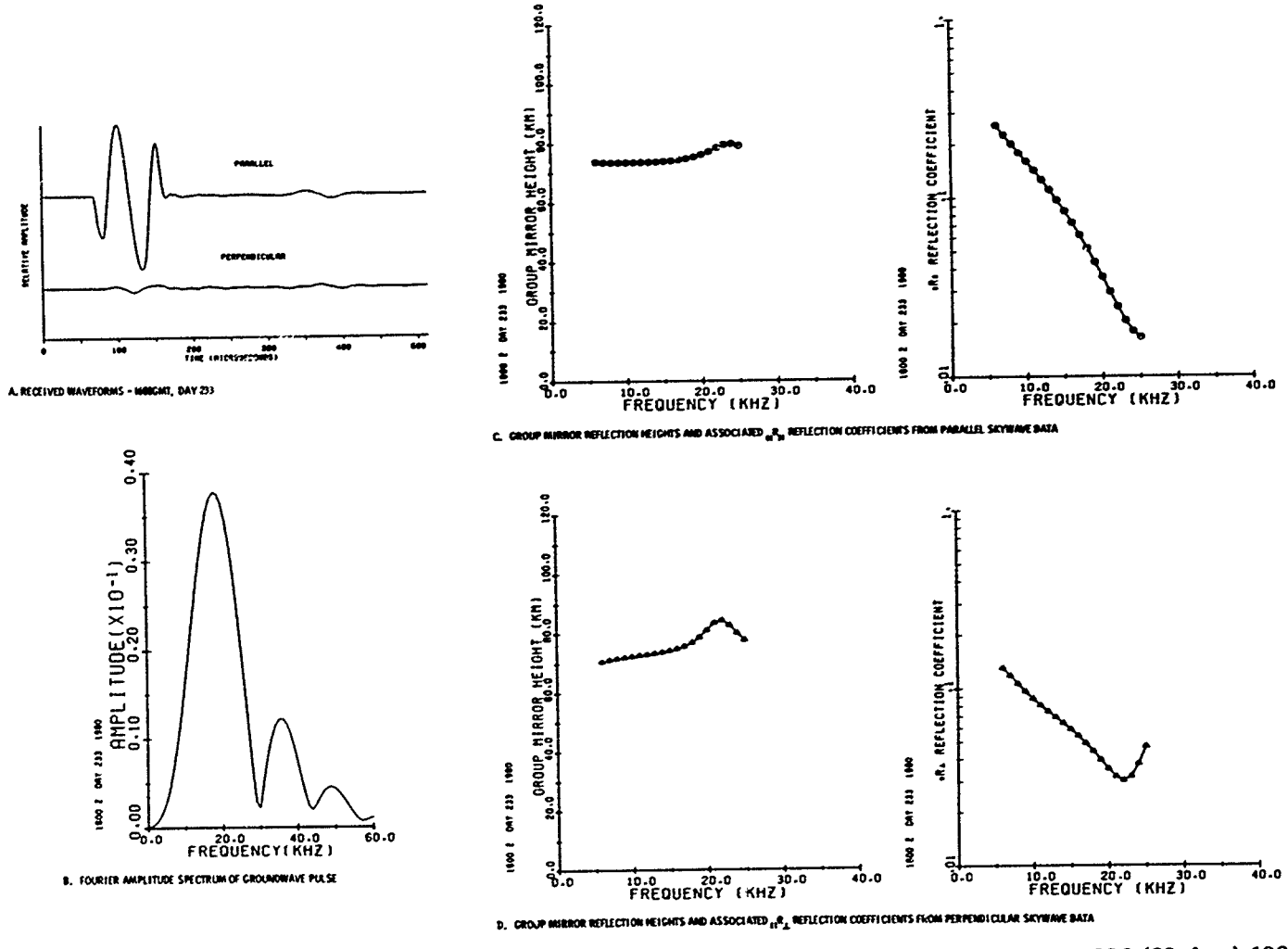

Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 230 (17 Aug) — DAY 236 (23 Aug) 1980

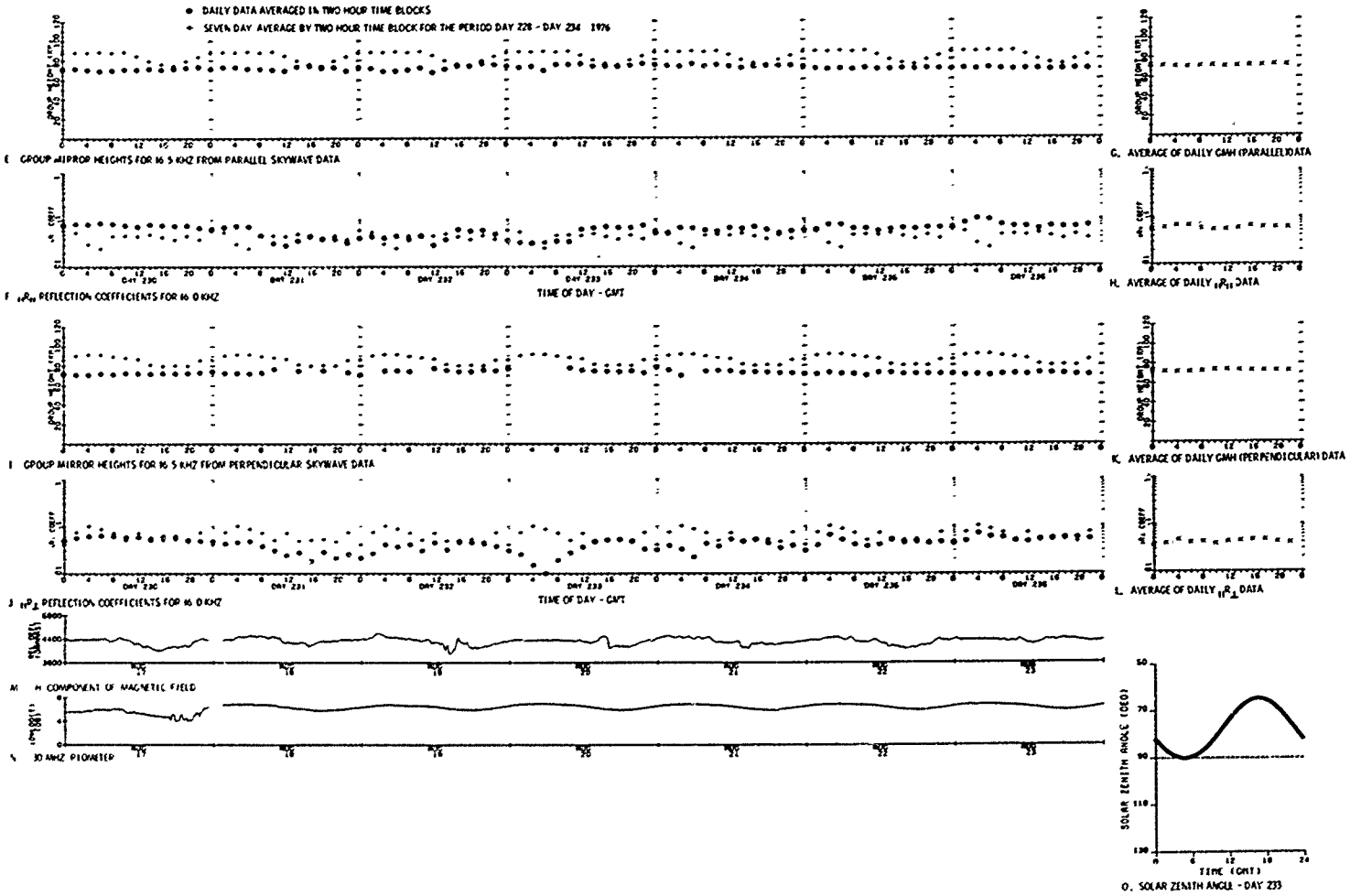

Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 230 (17 Aug) — DAY 236 (23 Aug) 1980 (Cont)

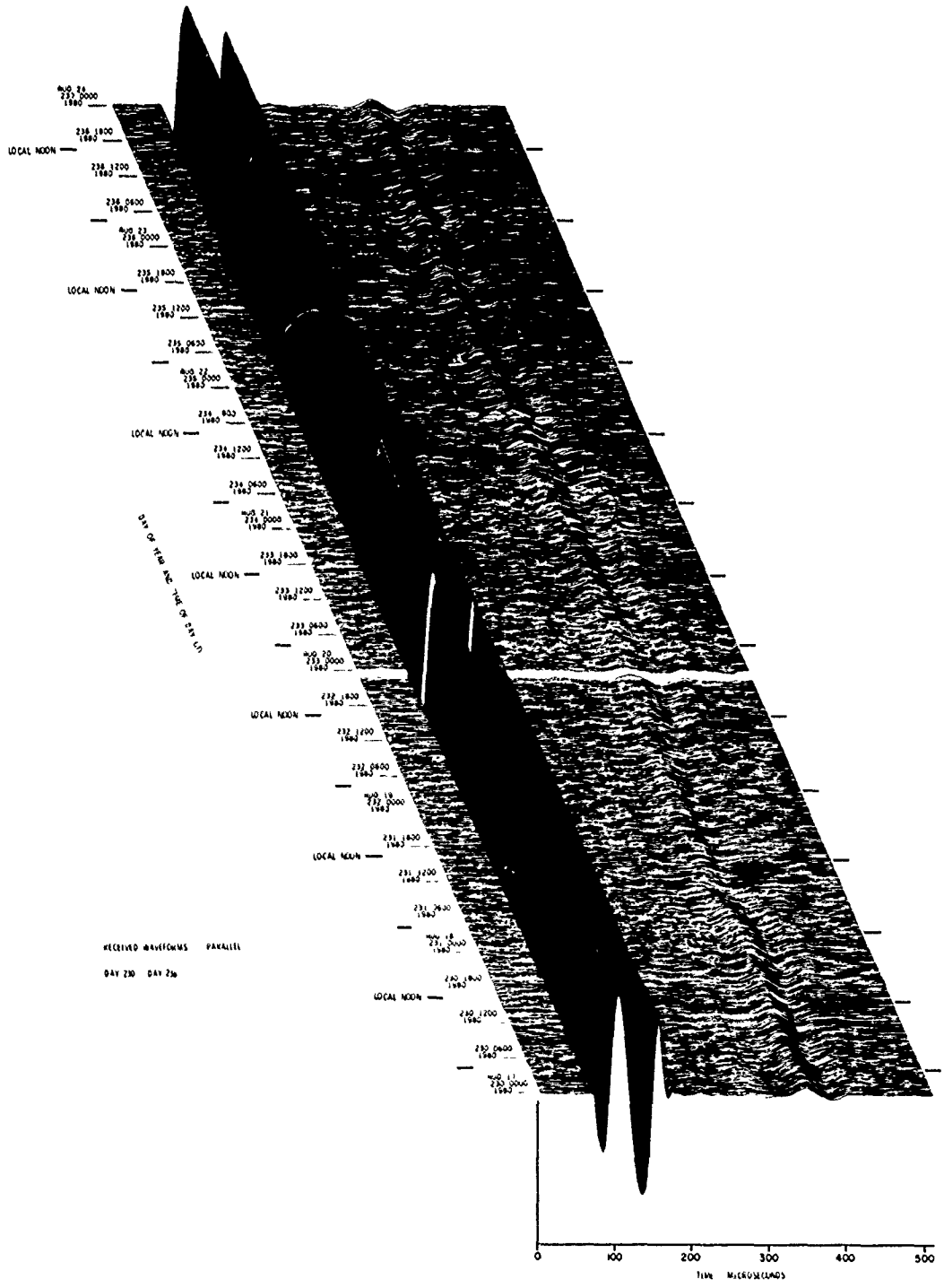

Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 230 (17 Aug) – DAY 236 (23 Aug) 1980 (Cont)
Part R. || Waveform Display

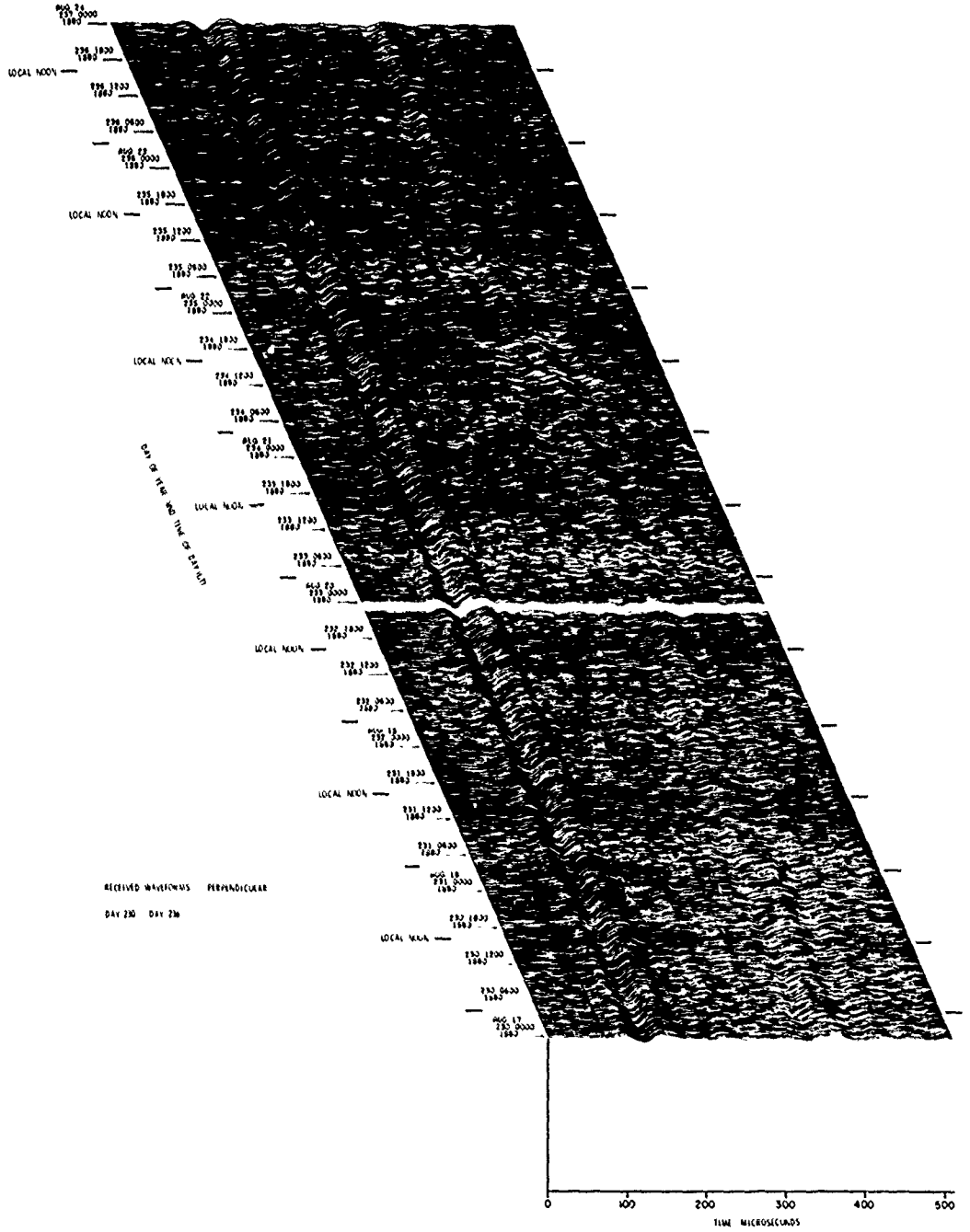

Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 230 (17 Aug) – DAY 236 (23 Aug) 1980 (Cont)
Part S. $\perp$ Waveform Display

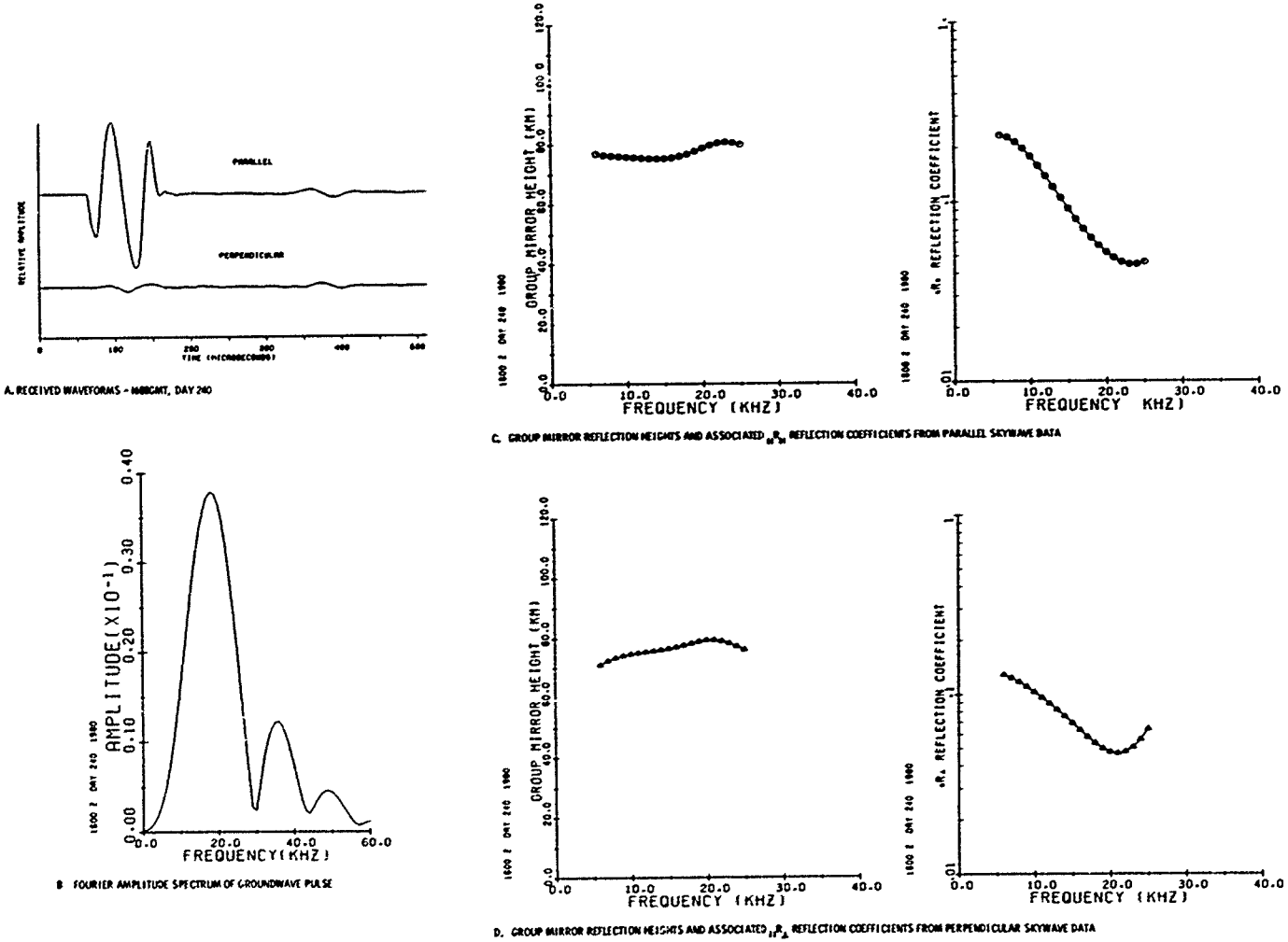

Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 237 (24 Aug) — DAY 243 (30 Aug) 1980

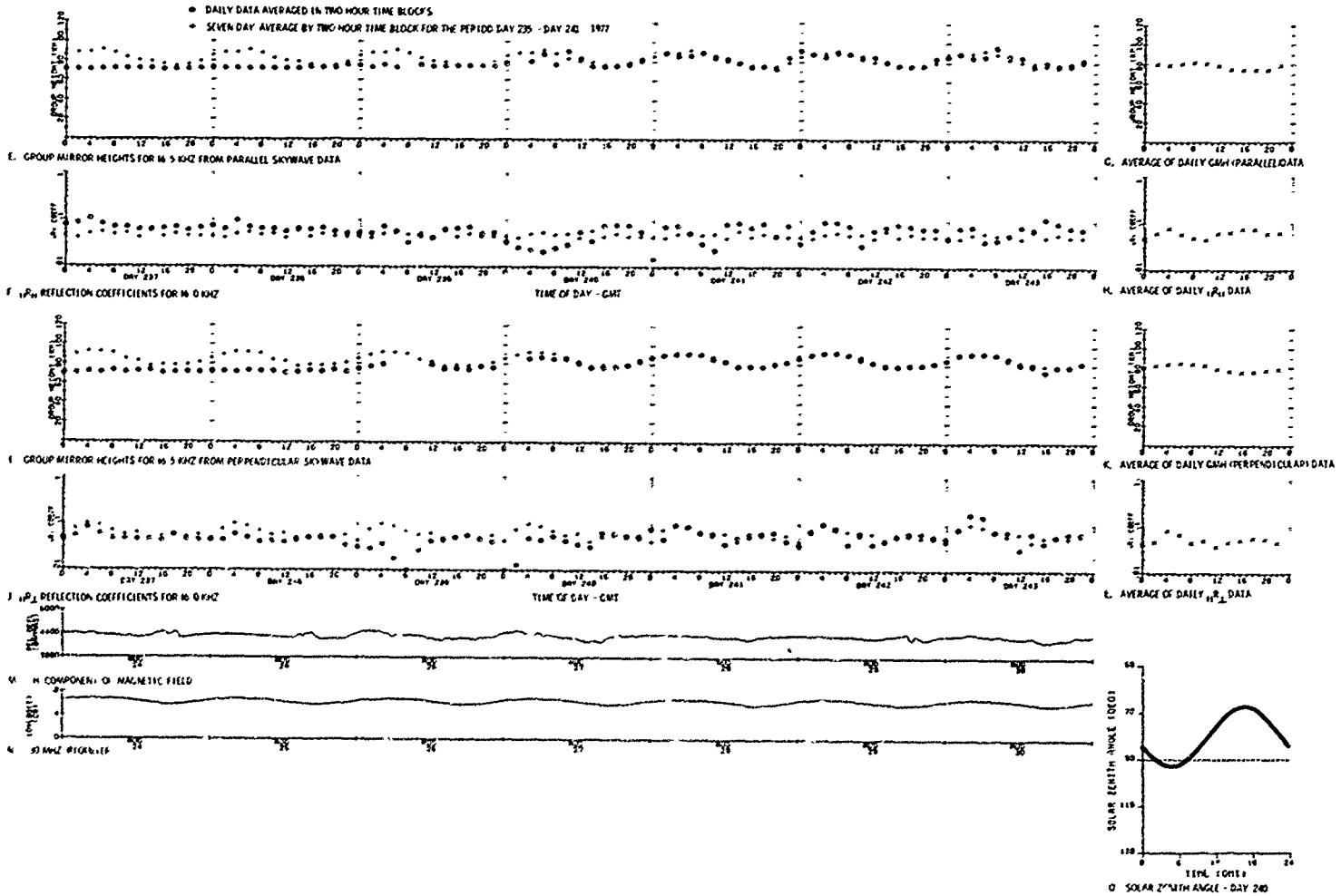

Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 237 (24 Aug) – DAY 243 (30 Aug) 1980 (Cont)

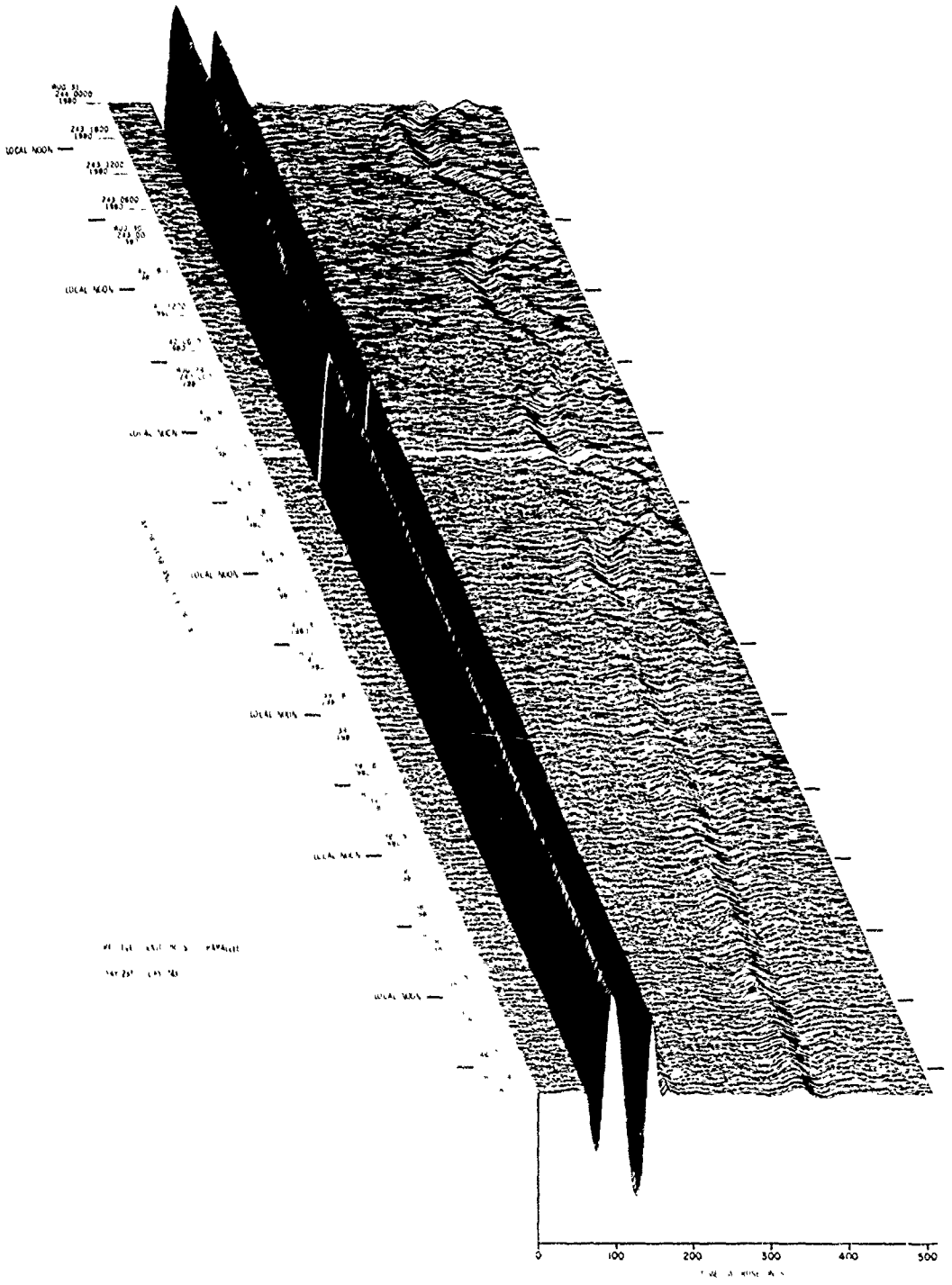

Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 237 (24 Aug) – DAY 243 (30 Aug) 1980 (Cont)
Part R. || Waveform Display

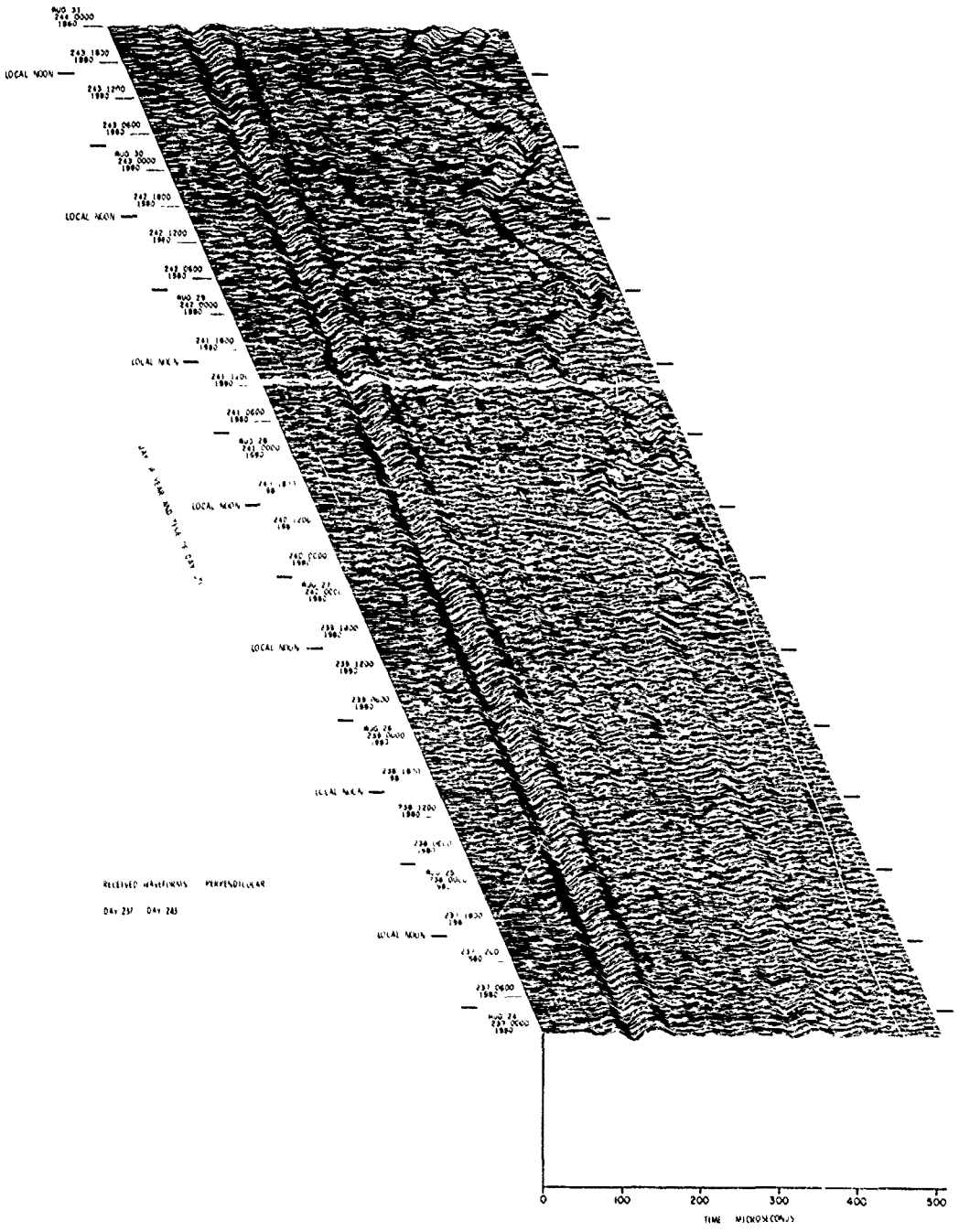

Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 237 (24 Aug) – DAY 243 (30 Aug) 1980 (Cont)
Part S. ⊥ Waveform Display

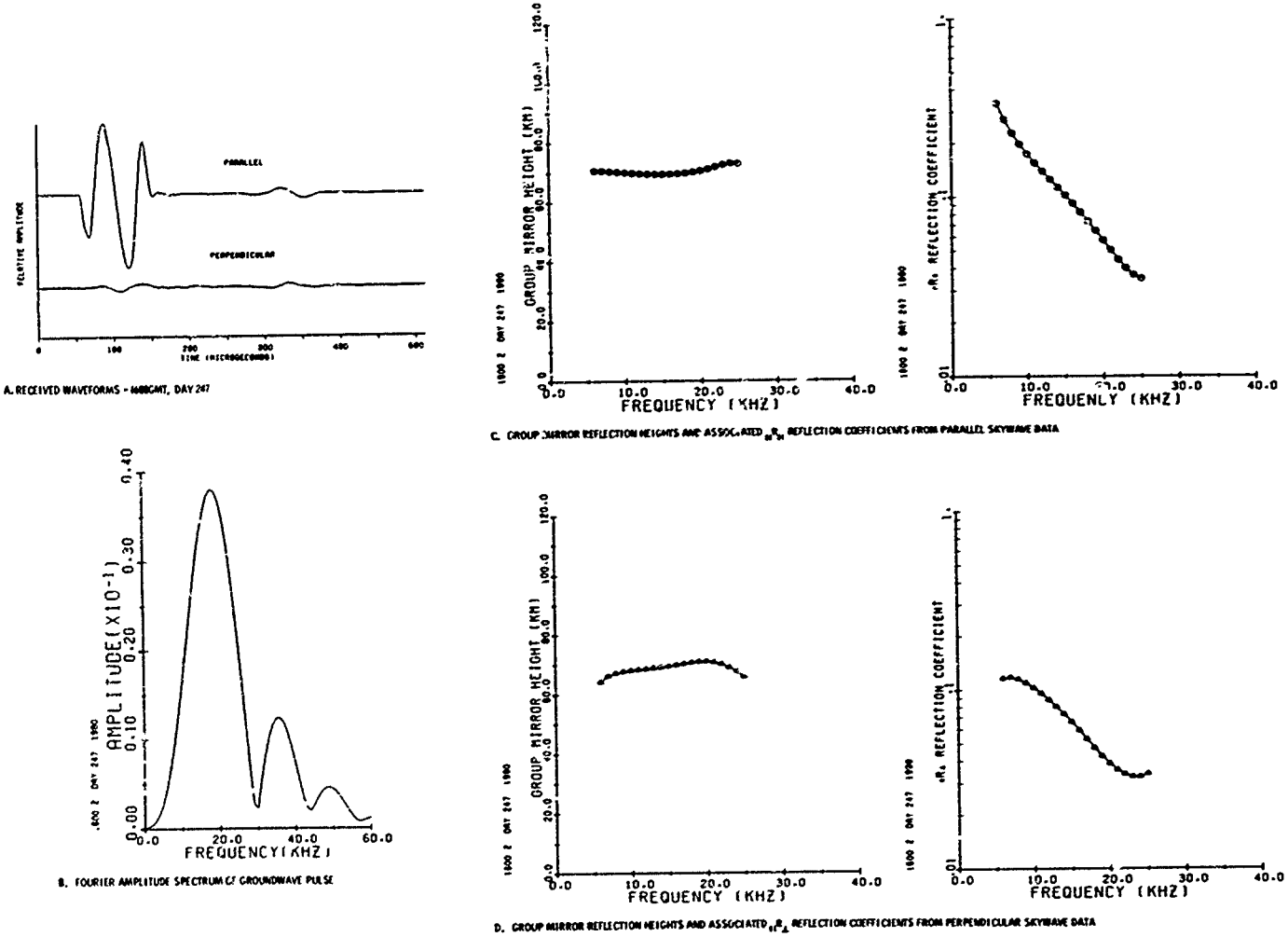

Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 244 (31 Aug) — DAY 250 (6 Sep) 1980

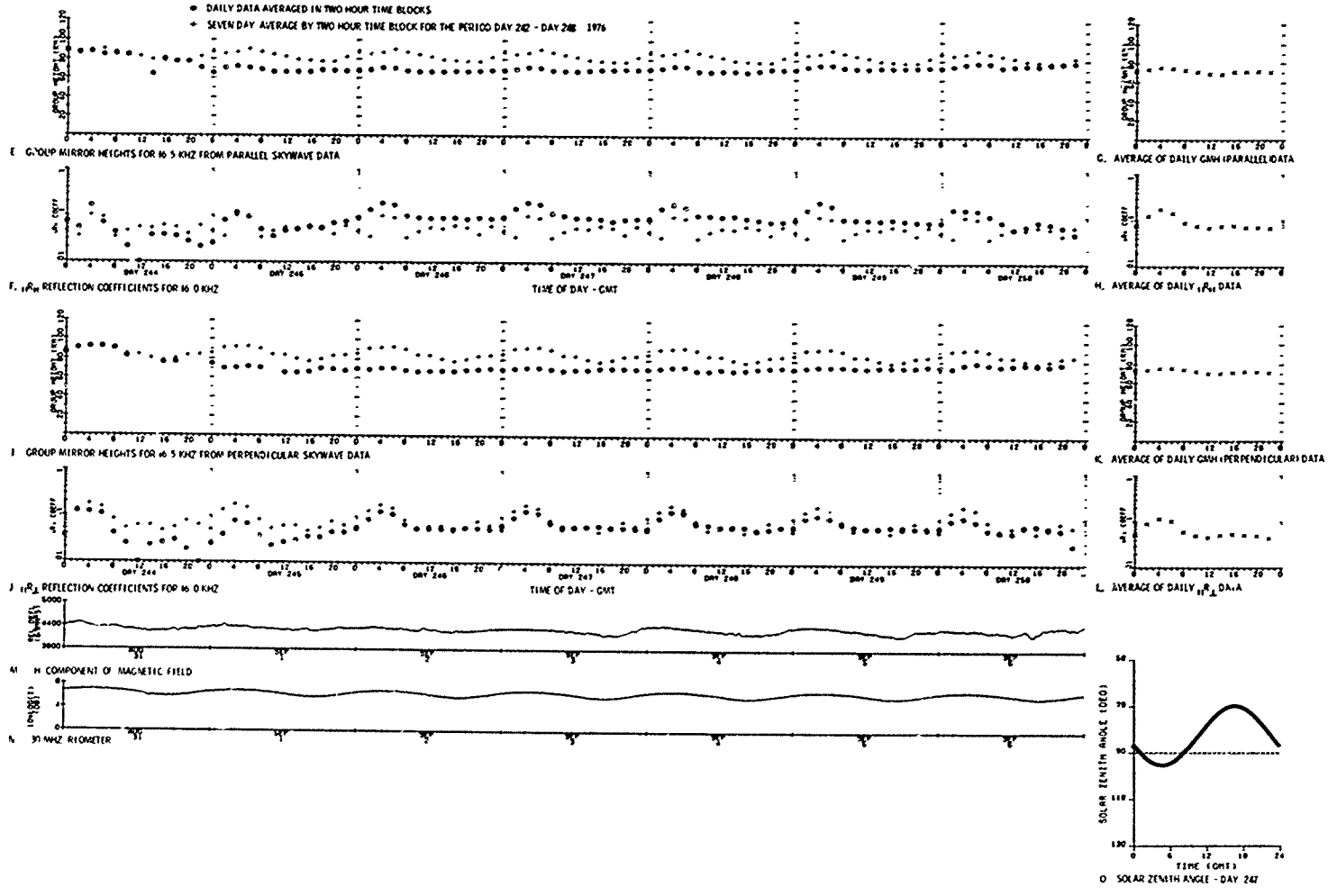

Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 244 (31 Aug) — DAY 250 (6 Sep) 1980 (Cont)

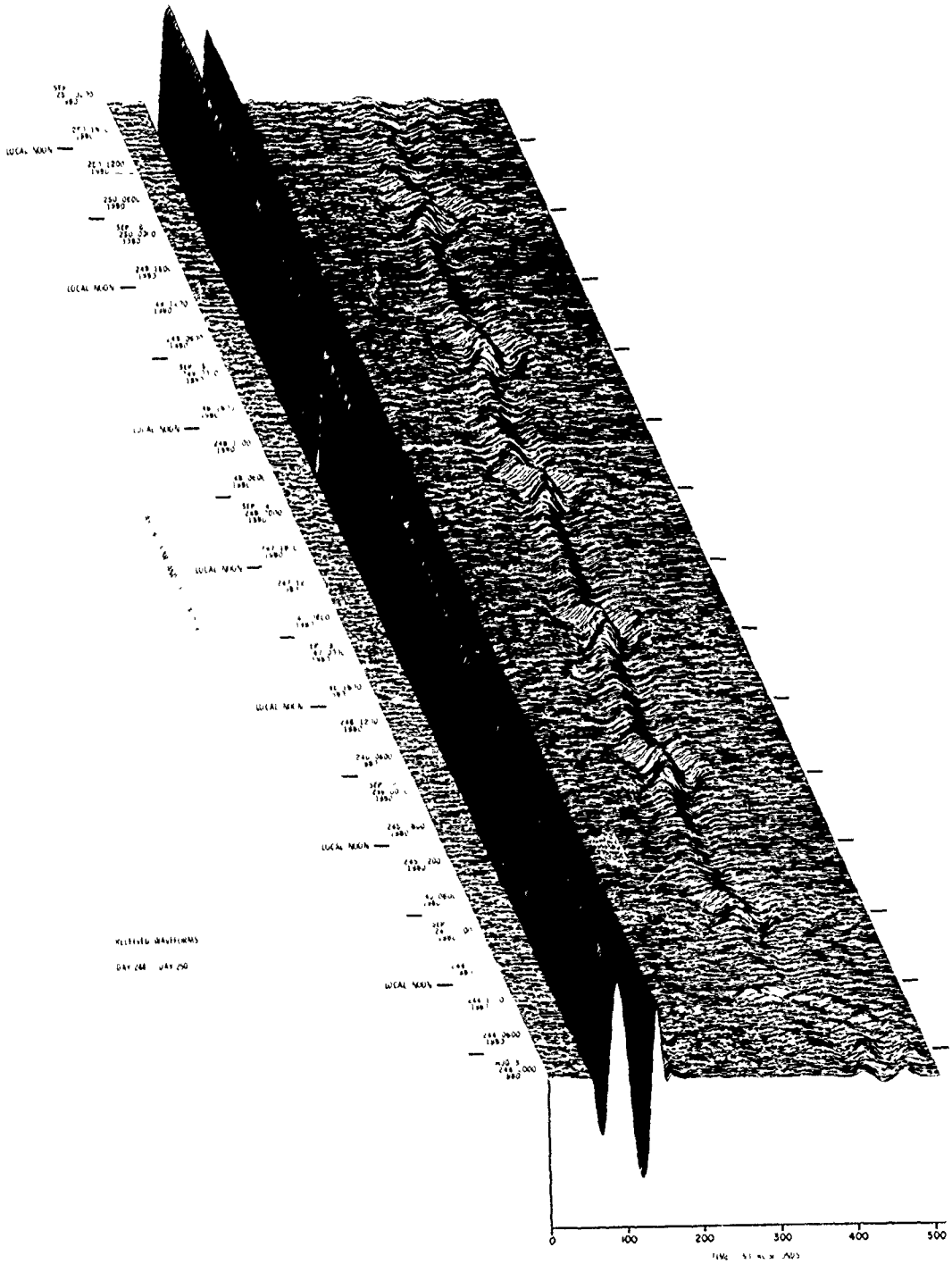

Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 244 (31 Aug) – DAY 250 (6 Sep) 1980 (Cont)
Part R. ||Waveform Display

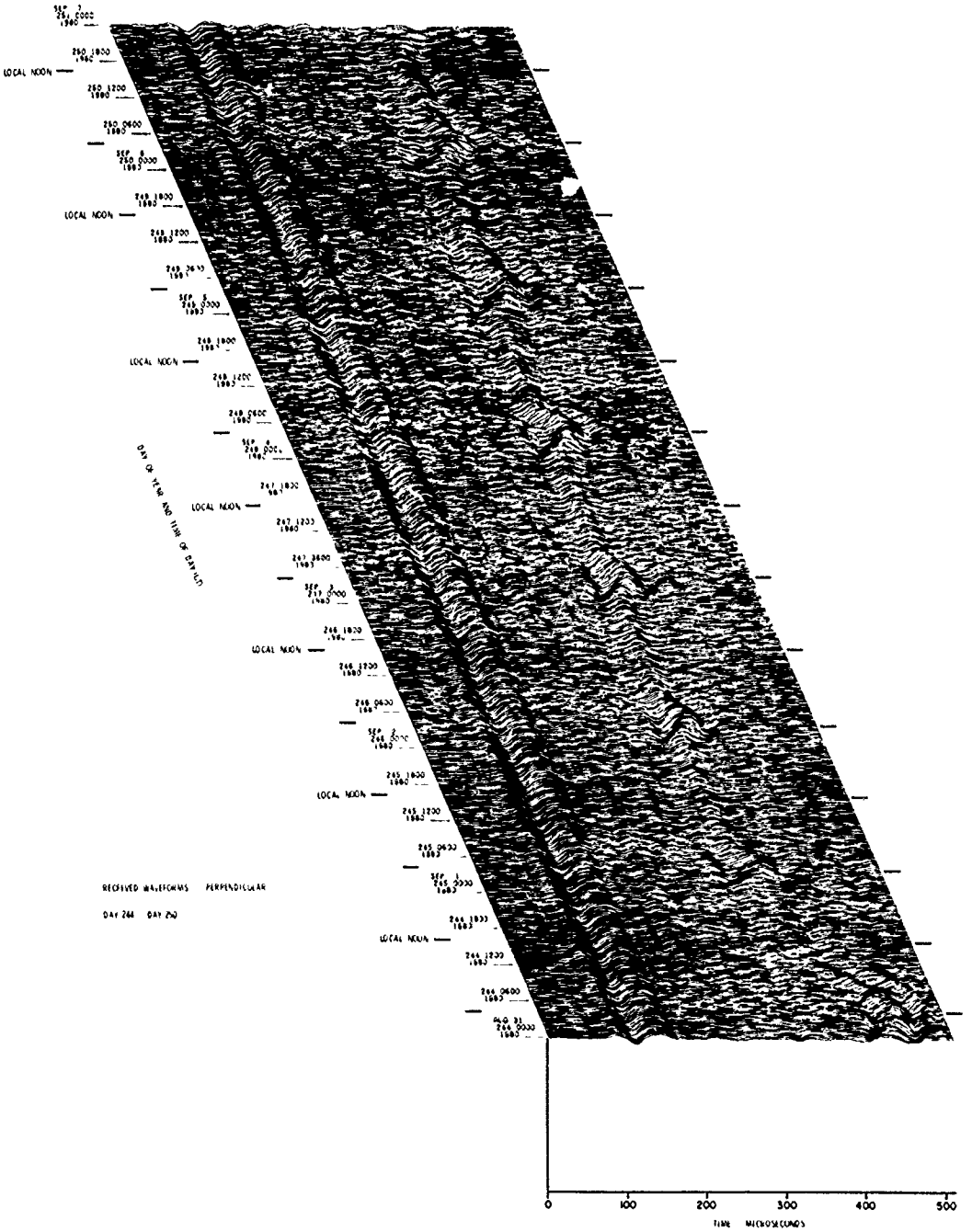

Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 244 (31 Aug) – DAY 250 (6 Sep) 1980 (Cont)
Part S. ⊥ Waveform Display

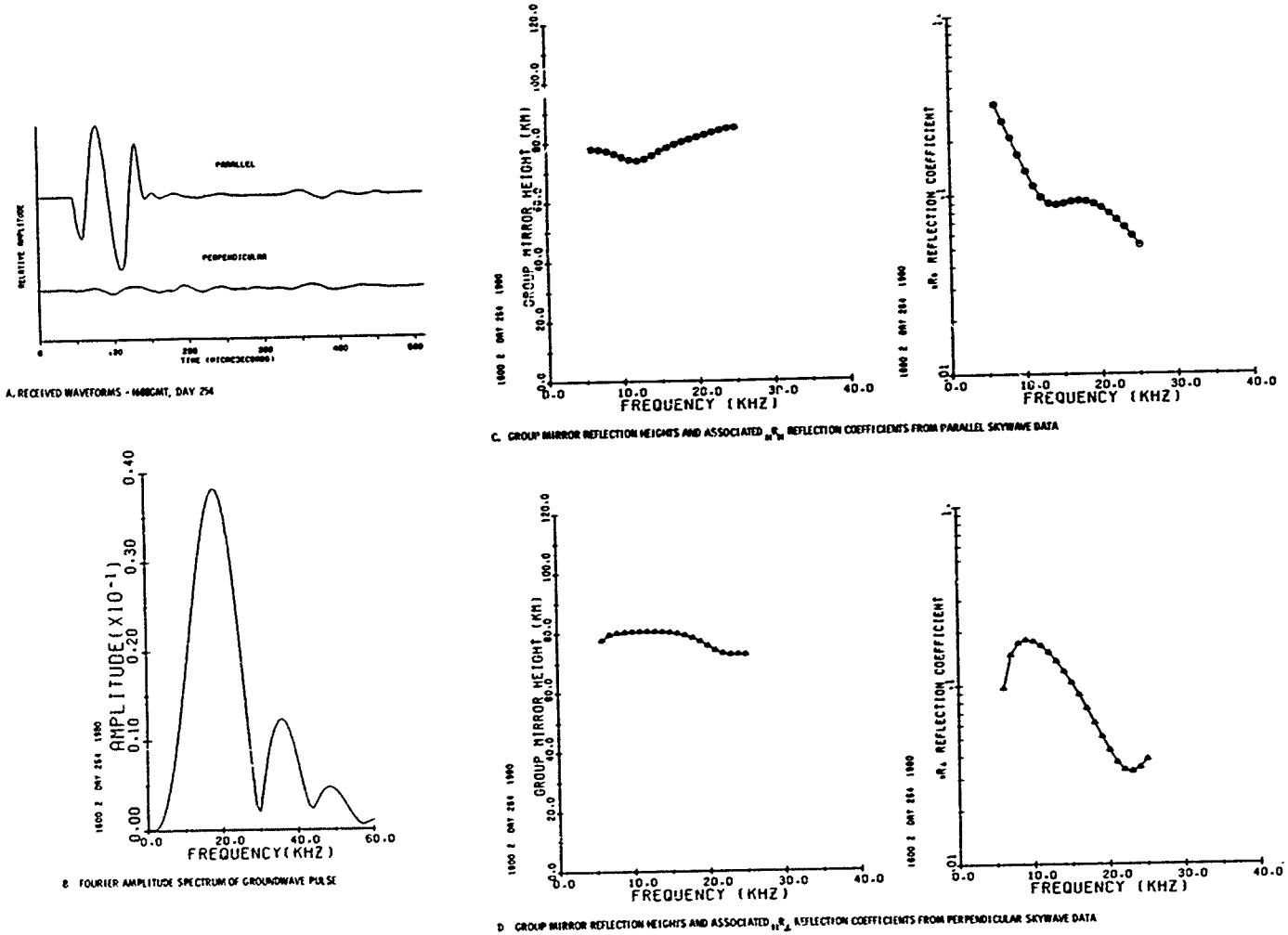

Figure 21. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 251 (7 Sep) — DAY 257 (13 Sep) 1980

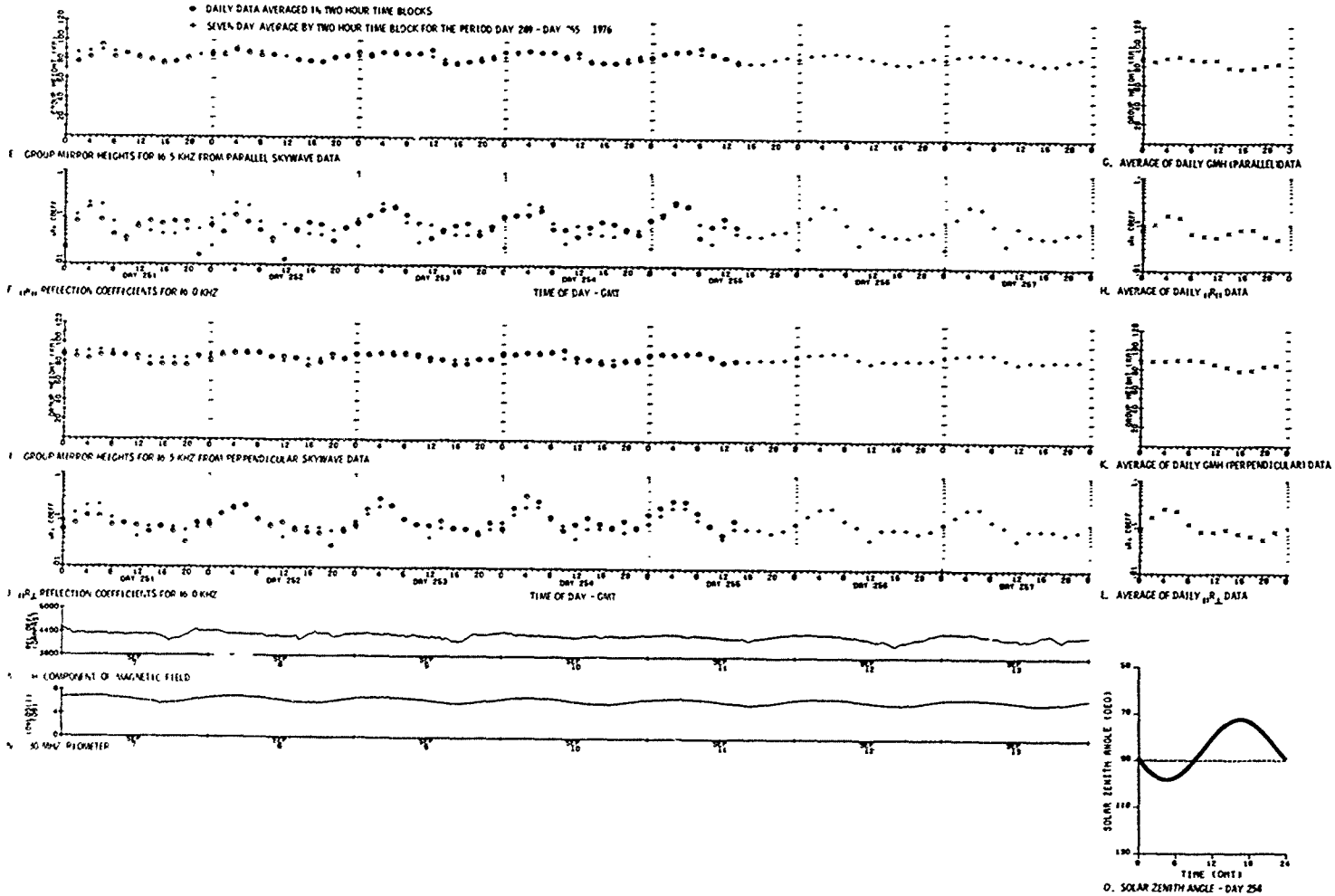

Figure 21. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 251 (7 Sep) — DAY 257 (13 Sep) 1980 (Cont)

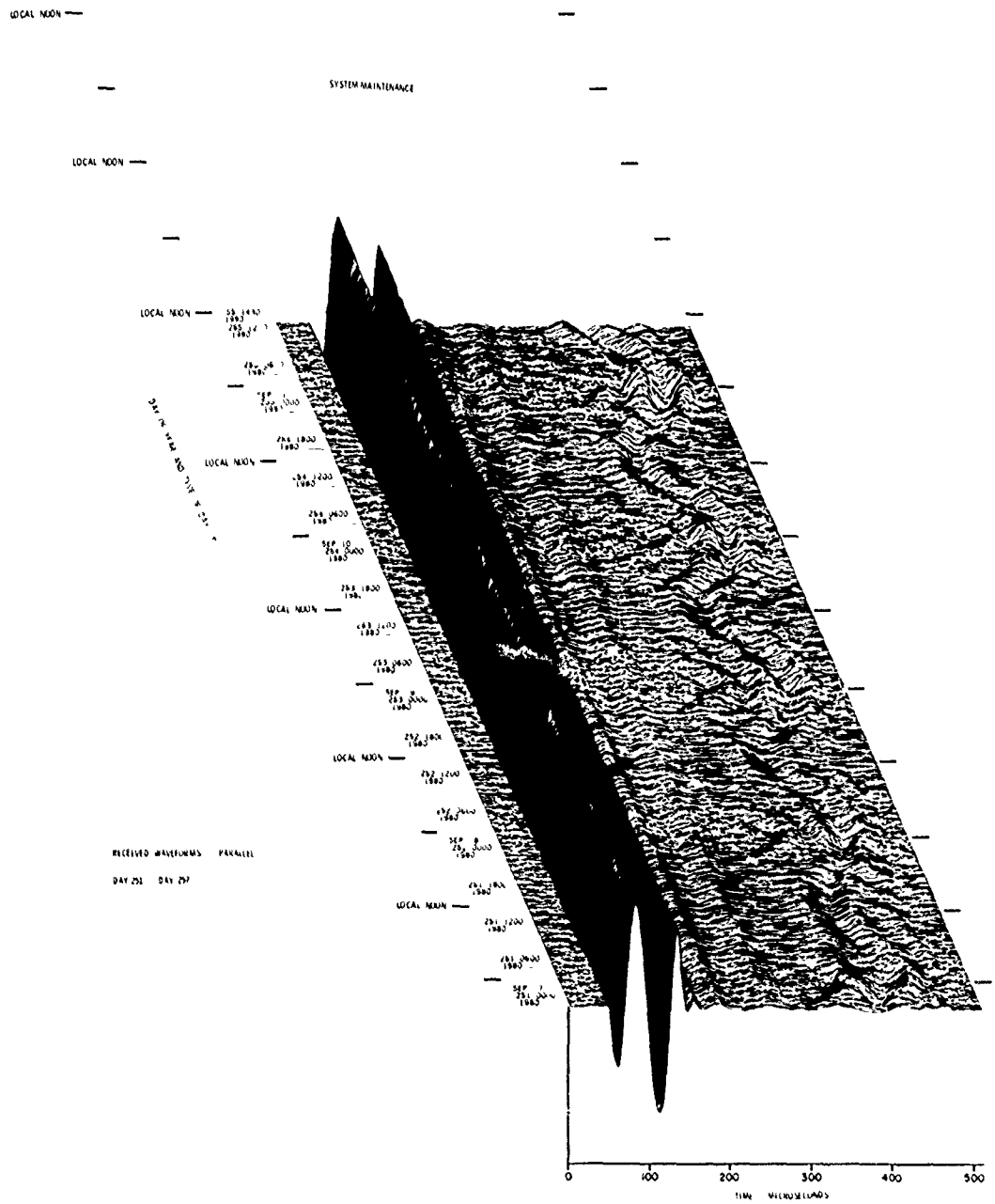

Figure 21. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 251 (7 Sep) — DAY 257 (13 Sep) 1980 (Cont)
Part R. II Waveform Display

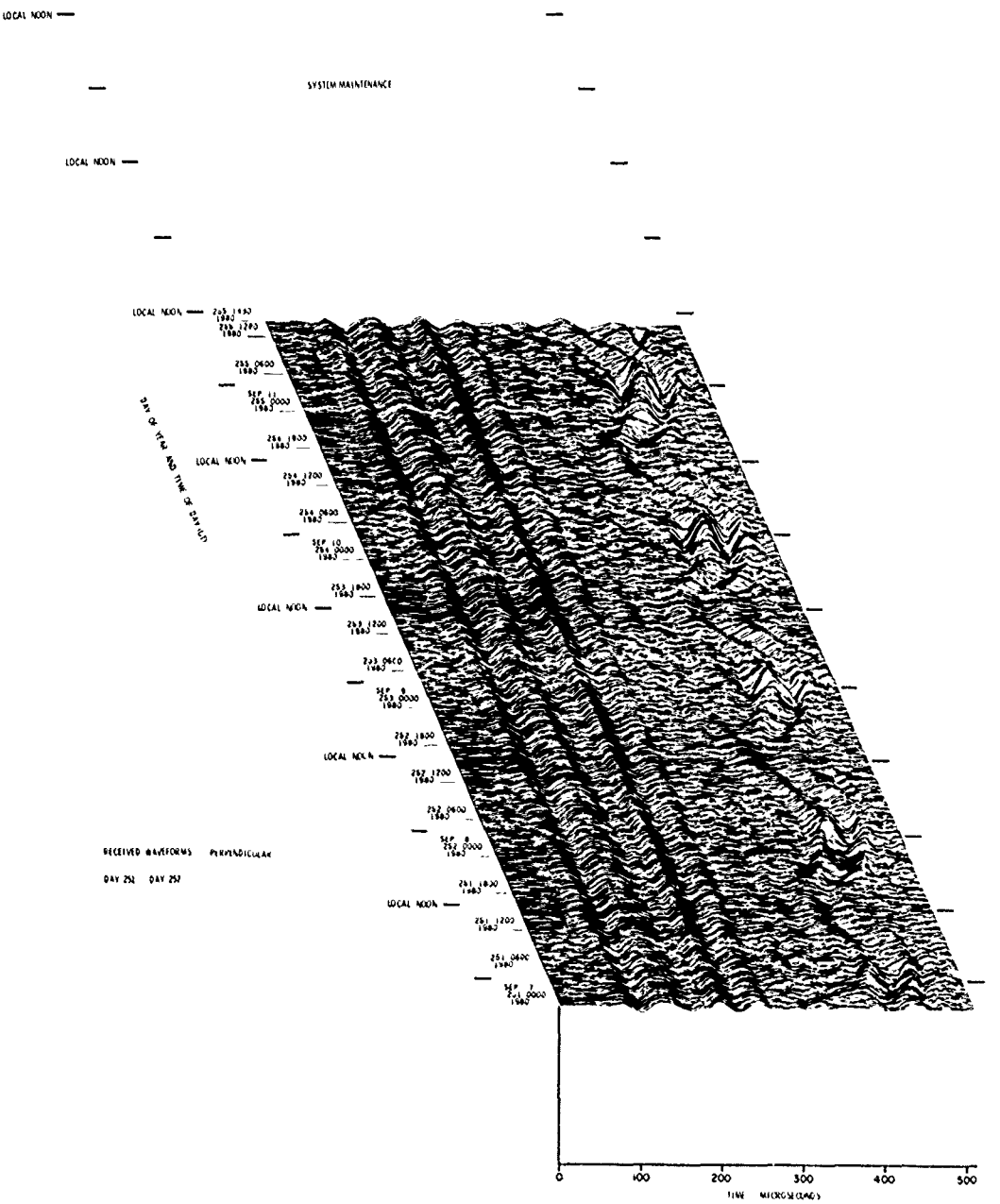

Figure 21. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 251 (7 Sep) – DAY 257 (13 Sep) 1980 (Cont)
Part S. ⊥ Waveform Display

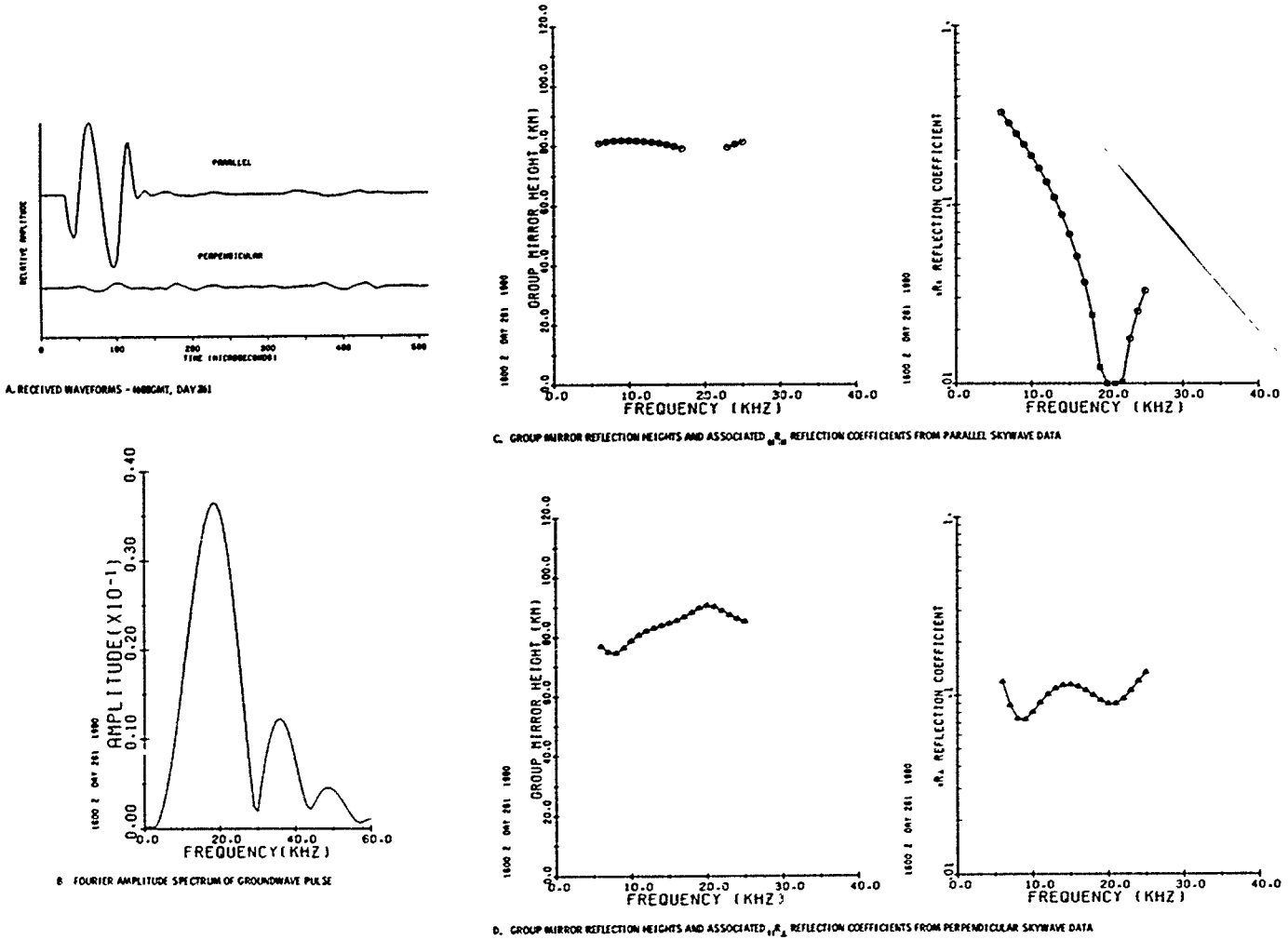

Figure 22. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 258 (14 Sep) — DAY 264 (20 Sep) 1980

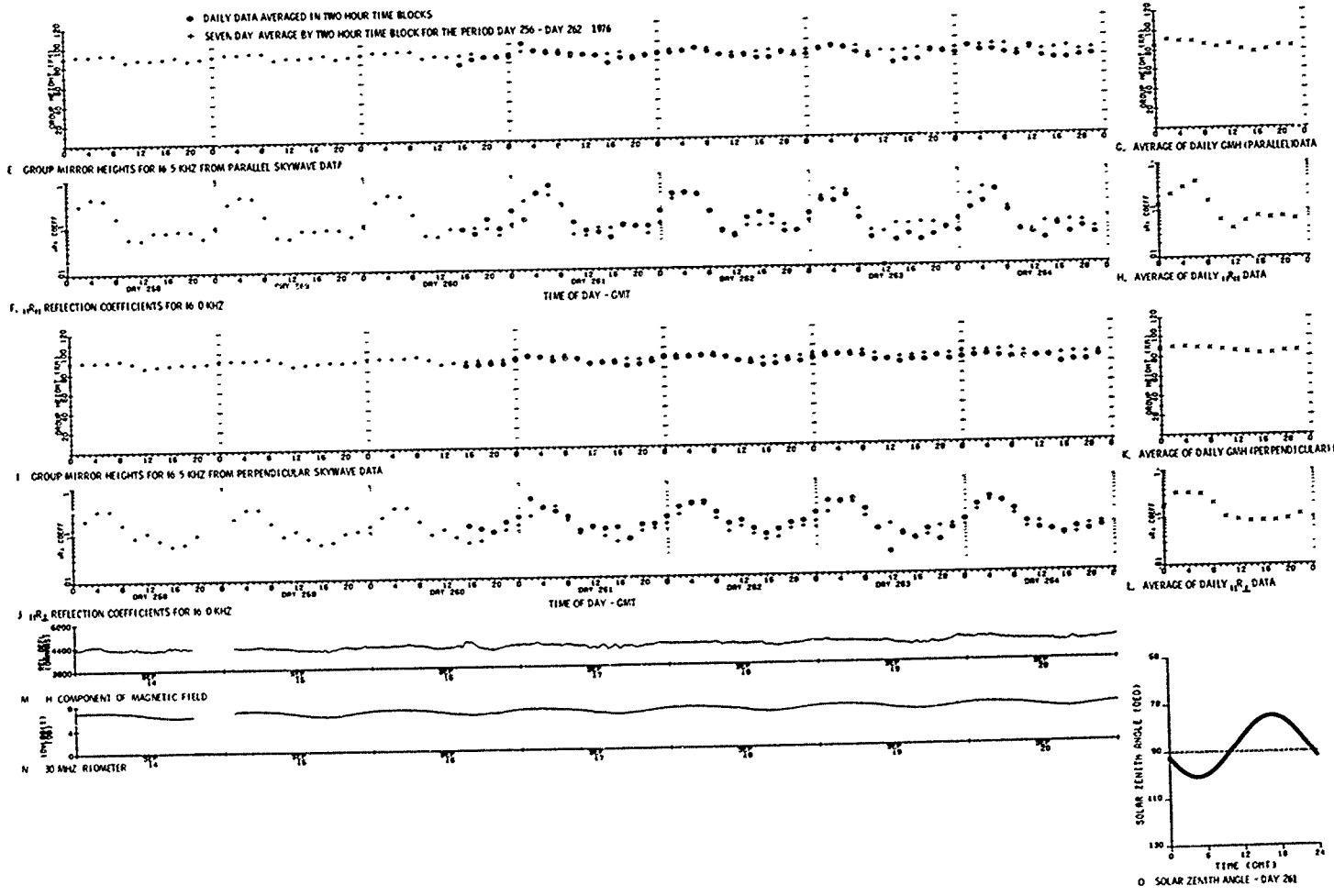

Figure 22. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 258 (14 Sep) – DAY 264 (20 Sep) 1980 (Cont)

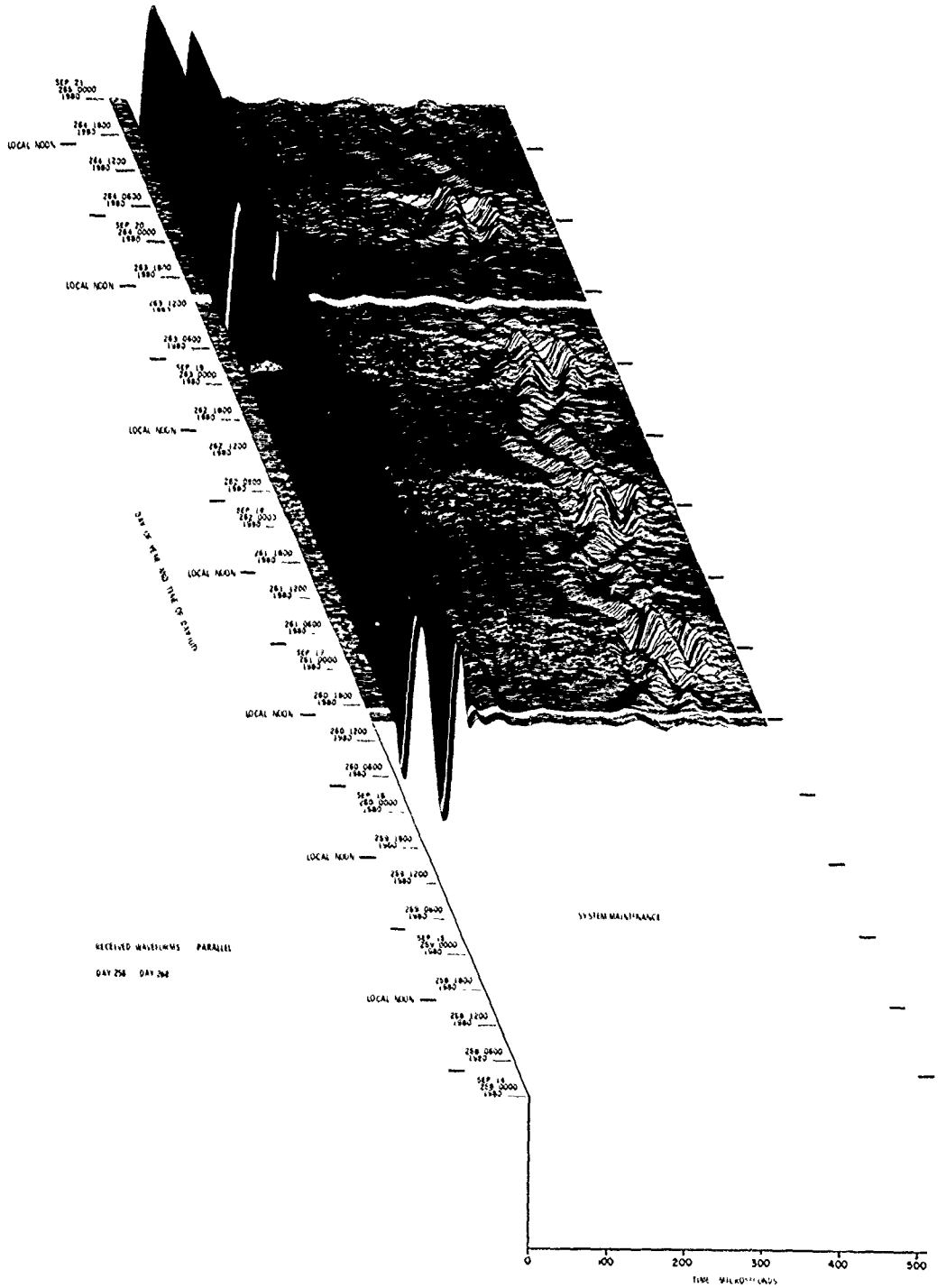

Figure 22. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 258 (14 Sep) – DAY 264 (20 Sep) 1980 (Cont)
Part R. ||Waveform Display

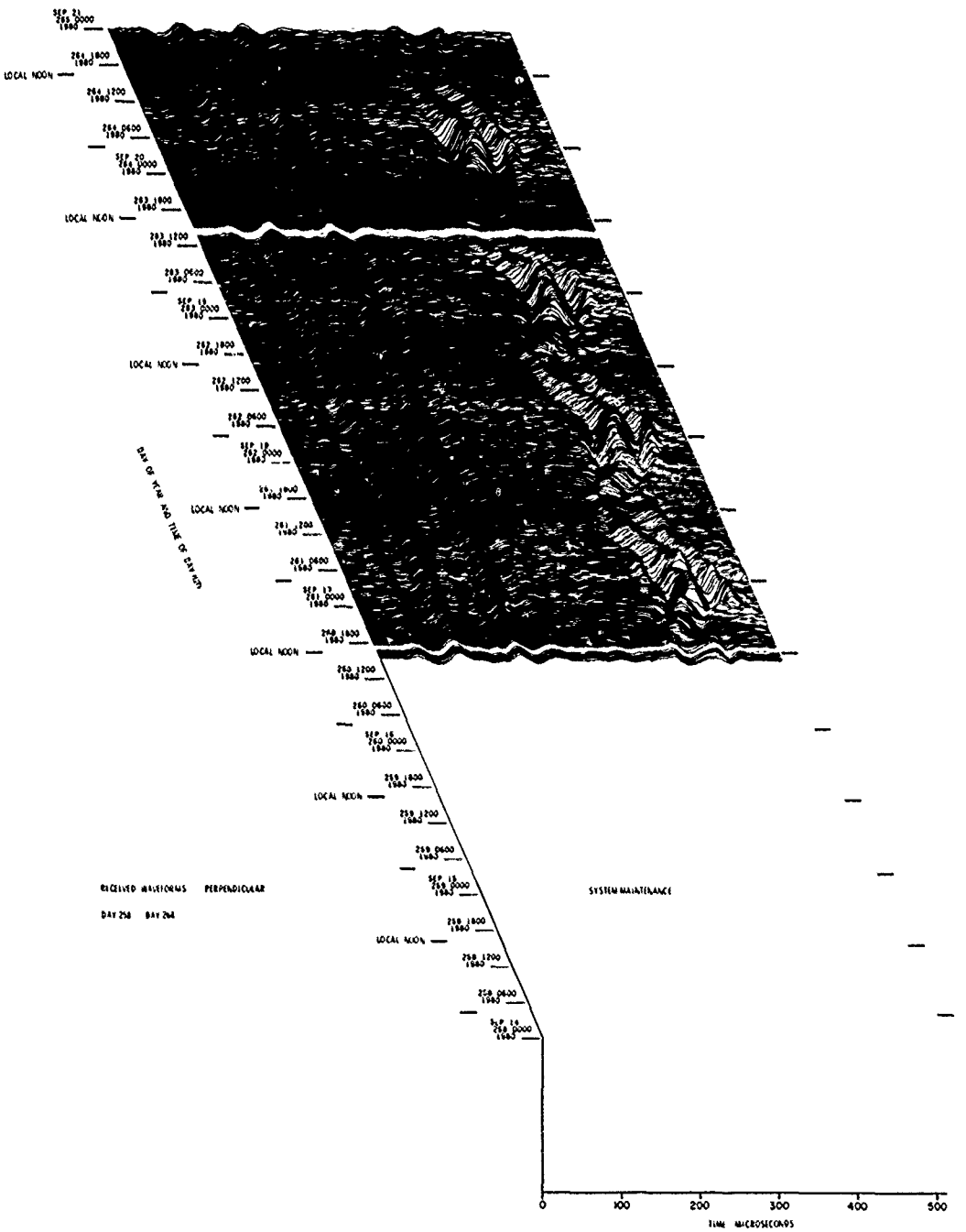

Figure 22. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 258 (14 Sep) – DAY 264 (20 Sep) 1980 (Cont)
Part S. ⊥ Waveform Display

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References

1. Lewis, E.A., Rasmussen, J.E., and Kossey, P.A. (1973) Measurements of ionospheric reflectivity from 6 to 35 kHz, J. Geophys. Res. 78:19.

2. Kossey, P.A., Rasmussen, J.E., and Lewis, E.A. (1974) VLF pulse ionosounder measurements of the reflection properties of the lower ionosphere, Akademie Verlaq, COSPAR, July.

3. Wait, J.R., and Howe, H.H. (1956) Amplitude and Phase Curves for Ground-Wave Propagation in the Band 200 Cycles per Second to 500 Kilocycles, Nat. Bur. Stand. U.S. Circ. No. 574.

4. Budden, K.G. (1961) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.

5. Rasmussen, J.E., McLain, R.J., Capt, USAF, and Turtle, J.P. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 19 January – 2 March 1975, AFCRL-TR-76-0045, AD A022674.

6. Rasmussen, J.E., McLain, R.J., Capt, USAF, and Turtle, J.P. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 2 March – 3 May 1975, RADC-TR-76-146, AD A026465.

7. Rasmussen, J.E., McLain, R.J., Capt, USAF, Turtle, J.P., and Klemetti, W.I. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 4 May – 5 July 1975, RADC-TR-76-270, AD A034023.

8. Rasmussen, J.E., McLain, R.J., Capt, USAF, Turtle, J.P., and Klemetti, W.I. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 20 July – 20 September 1975, RADC-TR-76-327, AD A036913.

9. Rasmussen, J.E., McLain, R.J., Capt, USAF, Turtle, J.P., and Klemetti, W.I. (1976) VLF/LF Reflectivity of the Polar Ionosphere, 21 September – 3 January 1976, RADC-TR-76-378, AD A037794.

10. Rasmussen, J.E., Turtle, J.P., Pagliarulo, R.P., and Klemetti, W.I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 4 January – 3 July 1976, RADC-TR-77-68, AD A040920.

11. Rasmussen, J.E., Turtle, J.P., Pagliarulo, R.P., and Klemetti, W.I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 1 August 1976 – 1 January 1977, RADC-TR-77-141, AD A044050.

12. Rasmussen, J.E., Turtle, J.P., Pagliarulo, R.P., and Klemetti, W.I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 2 January – 30 April 1977, RADC-TR-77-251, AD A047238.

13. Rasmussen, J.E., Turtle, J.P., Pagliarulo, R.P., and Klemetti, W.I. (1977) VLF/LF Reflectivity of the Polar Ionosphere, 1 May – 3 September 1977, RADC-TR-77-428, AD A053236.

14. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., and Klemetti, W.I. (1978) VLF/LF Reflectivity of the Polar Ionosphere, 4 September – 31 December 1977, RADC-TR-78-95, AD A060918.

15. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., and Klemetti, W.I. (1978) VLF/LF Reflectivity of the Polar Ionosphere, 1 January – 22 April 1978, RADC-TR-78-186, AD A062534.

16. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., Cooley, R.L., TSgt, and Klemetti, W.I. (1979) VLF/LF Reflectivity of the Polar Ionosphere, 23 April – 2 September 1978, RADC-TR-79-100, AD A074762.

17. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., Cooley, R.L., TSgt, and Klemetti, W.I. (1979) VLF/LF Reflectivity of the Polar Ionosphere, 3 September – 30 December 1978, RADC-TR-79-178.

18. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., Cooley, R.L., TSgt, and Klemetti, W.I. (1979) VLF/LF Reflectivity of the Polar Ionosphere, 31 December – 5 May 1979, RADC-TR-79-273, AD A083240.

19. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., Cooley, R.L., TSgt, and Klemetti, W.I. (1980) VLF/LF Reflectivity of the Polar Ionosphere, 6 May – 1 September 1979, RADC-TR-80-12, AD A091091.

20. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., and Klemetti, W.I. (1980) VLF/LF Reflectivity of the Polar Ionosphere, 2 September – 22 December 1979, RADC-TR-80-189.

21. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., and Klemetti, W.I. (1980) VLF/LF Reflectivity of the Polar Ionosphere, 6 January – 3 May 1980, RADC-TR-80-298, AD A094104.

22. Turtle, J.P., Rasmussen, J.E., Klemetti, W.I. (1980) Effects of Energetic Particle Events on VLF/LF Propagation Parameters, 1974-1977, RADC-TR-80-307.

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